

Micro Auto Gasification System:

Emission Characterization



MICRO AUTO GASIFICATION SYSTEM: EMISSIONS CHARACTERIZATION

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Abstract

A compact, container express (CONEX)-housed waste to energy unit, Micro Auto Gasification System (MAGS), was characterized for air emissions from burning of types of military waste as a preliminary characterization of potential gasification emissions. The MAGS unit is a dual chamber gasifier with a secondary diesel-fired combustor. Eight tests were conducted with multiple types of waste in a seven-day period at the Kilauea Military Camp in Hawai'i in July of 2015. The emissions characterized were chosen based on regulatory emission limits as well as their ability to cause adverse health effects in humans: particulate matter (PM), mercury, heavy metals, volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). Three compositions of military waste feedstock reflecting the variety of wastes to be encountered in the theatre were investigated: standard waste (SW), standard waste with increased plastic content (HP), standard waste without SW food components but added first strike ration (FSR) food and packaging material (termed FSR). A fourth waste was collected from the Kilauea dumpster that served the dining facility and room lodging (KMC). Limited scrubber water and solid ash residue samples were collected to obtain a preliminary characterization of these effluents/residues.

Gasifying SW, HP, and KMC resulted in similar PCDD/PCDF stack concentrations, 0.26-0.27 ng Toxicity Equivalence (TEQ)/m³ at 7% O₂, while FSR waste generated a notably higher stack concentration of 0.68 ng TEQ/m³ at 7% O₂. The PM emissions, similarly, were higher from gasification of the FSR waste composition, 60 mg/m³ at 7% O₂, than the other waste composition types, 18-41 mg/m³ at 7% O₂. The mercury concentration was lower when gasifying waste with the higher plastic content (HP), 0.31±0.037 µg/m³ at 7% O₂, than the other waste types, 0.53-0.73 µg/m³ at 7% O₂. Benzene, toluene, and propene were the most abundant VOCs in all waste types. Higher levels of vinyl chloride, vinyl acetate, and chloromethane from gasification of FSR waste were found in the stack gas, which may be due to higher salt content in the FSR food and/or the addition of FSR packaging material.

Five of the nine EPA-regulated elements/compounds (lead (Pb), cadmium (Cd), mercury (Hg), sulfur dioxide (SO₂), and hydrogen chloride (HCl)) from the MAGS were under the set emission limits for Other Solid Waste Incineration Units (OSWI, <https://www3.epa.gov/ttn/atw/129/oswi/fr16de05.pdf>, accessed 8/12/2016). The PCDD/PCDF, PM, NO_x, and CO stack emissions from the MAGS were all above the current federal emissions limits. The PM emissions factors, however, were 39 and 100 times lower from the MAGS unit than from published data on burning simulated military waste in an air curtain incinerator and in open burn piles, respectively, while the PCDD/PCDF emissions were 9 and 460 times lower.

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Appendix F: PAHs – Full data set

List of Acronyms

ACC	U.S. Air Force Combat Command
acfm	Actual cubic feet per min
ARL	U.S. Army Research Laboratory
BC	Black carbon
Cd	Cadmium
CEM	Continuous emission monitor
CH ₄	Methane
CO	Carbon monoxide
CO ₂	Carbon dioxide
Cu	Copper
CV	Coefficient of variance
DOD	U.S. Department of Defense
dscm	Dry standard cubic meter
EPA	U. S. Environmental Protection Agency
EXWC	(Naval Facilities Engineering Command) Engineering and Expeditionary Warfare Center
Fe	Iron
FMS	Fluid Management Systems
FSR	First strike ration
FTIR	Fourier transform infrared
GC	Gas chromatograph/y
H ₂	Hydrogen
HAP	Hazardous air pollutant
HCl	Hydrogen chloride
HDPE	High density polyethylene
Hg	Mercury
Hg ⁰	Elemental mercury
HP	High plastic waste
HRGC	High Resolution Gas Chromatography
HRMS	High Resolution Mass Spectrometry
IARC	International Agency for Research on Cancer
ICP	Inductively coupled plasma (spectroscopy)
JDW2E	Joint Deployable Waste to Energy
KMC	Kilauea Military Camp
LBNL	Lawrence Berkeley National Laboratory
LDPE	Low density polyethylene
LRMS	Low resolution mass spectrometer
MAGS	Micro Auto Gasification System
MCE	Modified combustion efficiency
MDL	Method detection limit
MRL	Method reporting limit
MS	Mass spectrometry
NDIR	Non-dispersive infrared

NECC	(U.S.) Navy Expeditionary Combat Command
NIST	National Institute for Standards and Technology
NO	Nitrogen oxide
NO ₂	Nitrogen dioxide
NO _x	Nitrogen oxides
NSRDEC	Natick Soldier Research, Development and Engineering Center
O ₂	Oxygen
ORNL	Oak Ridge National Laboratory
OSWI	Other Solid Waste Incinerator
PAH	Polycyclic aromatic hydrocarbon
PCF	Photometric correction factor
PET	Polyethylene terephthalate
Pb	Lead
PCDD	Polychlorinated dibenzo- <i>p</i> -dioxin
PCDF	Polychlorinated dibenzofuran
PM	Particulate matter
PM FSS	(U.S. Army) Product Manager Force Sustainment Systems
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinylchloride
QA	Quality assurance
QC	Quality control
RD&E	Research, Development & Engineering
RH	Relative humidity
RPD	Relative percent difference
scfm	standard cubic foot/feet per minute
SO ₂	Sulfur dioxide
SSC PAC	Space and Naval Warfare Systems Center Pacific
STDV	Standard deviation
SW	Standard waste
TEF	Toxic Equivalence Factor
TEQ	Toxicity equivalence
TROPEC	Transformative Reductions in Operational Energy Consumption
USPACOM	U.S. Pacific Command
VOC	Volatile organic compound
WTE	Waste to energy
XAD-2	Brand name of polymeric sorbent resin
XRF	X-ray fluorescence (spectrometry)

1 Introduction

1.1 Project Description and Objective

The purpose of this project was to provide preliminary characterization of the environmental emissions (air, water, and ash) that result from processing military camp waste in a waste to energy (WTE) gasification system. The intent was to provide environmental emissions information that will facilitate future permitting and operation of deployable WTE systems by joint U.S. forces. The gasification system was a previously utilized, pre-commercial model (version 6) Micro Auto Gasification System (MAGS) made available for this scoping program by the manufacturer, Terragon, Canada. The test was conducted at the Kilauea Military Camp (KMC), Hawai'i on the National Park Service grounds of Volcano National Park (Figure 1-1 and Figure 1-2).



Figure 1-1. Location of Kilauea Military Camp in Hawaii.



Figure 1-2. Map of Kilauea Military Camp.

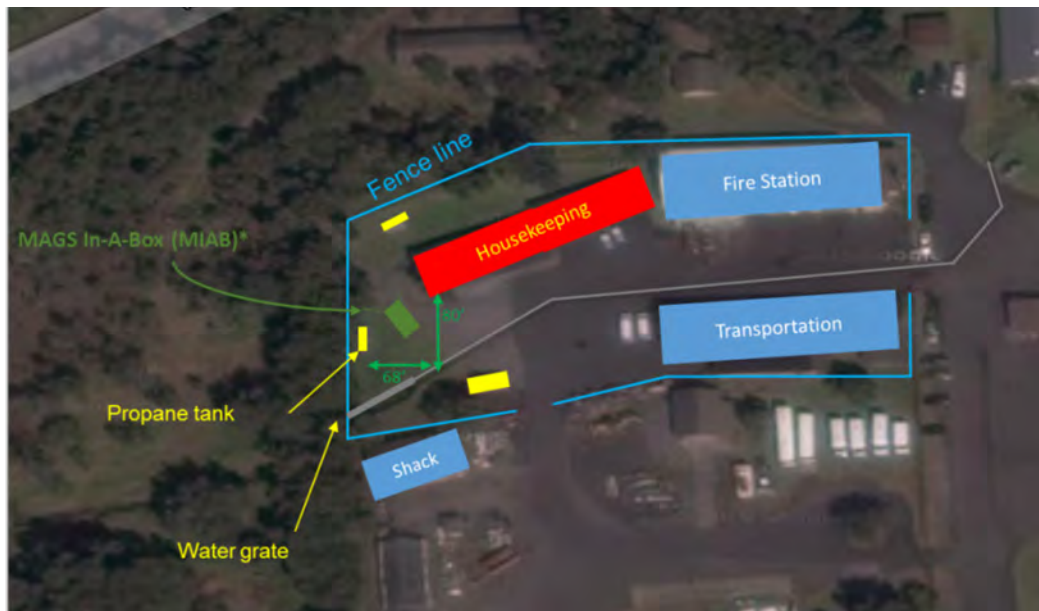


Figure 1-3. Location of MAGS unit at Kilauea Military Camp.

1.2 Background

The Department of Defense (DOD) has interest in solid waste management and disposal, particularly as these activities relate to operations in theatres overseas. Burn pits in expeditionary operations remain a significant waste disposal method due to their simplicity. However, smoke exposure may create deleterious health outcomes for burn pit operators and surrounding personnel. Likely due to these concerns, the National Defense Authorization Act of 2010, §317 (Public Law 111-84-Oct. 28, 2009) prohibited the use of open-air burn pits except where no alternative disposal method is feasible. Alternatively, incinerators employing waste combustion have been used to treat some of the overseas military waste. Gasification is an alternative to incineration and works by heating waste at high temperatures in the absence of primary combustion. Services within the DOD are assessing the feasibility of gasification to identify and assess burn pit alternatives and provide information needed to make informed decisions about waste management practices that efficiently and effectively improve force protection while being protective of health and meeting zero-waste objectives.

The MAGS assessment in Hawaii was a collaboration of two programs: the Joint Deployable Waste to Energy (JDW2E) and the Transformative Reductions in Operational Energy Consumption (TROPEC) programs. The team consisted of: U.S. Pacific Command (USPACOM) as Operational Manager; U.S. Army Natick Soldier Research, Development & Engineering Center (NSRDEC) as Technical Manager; and U.S. Army Product Manager Force Sustainment Systems (PM FSS), U.S. Navy Expeditionary Combat Command (NECC) and U.S. Air Force Combat Command (ACC) as Transition Managers. The vision of the TROPEC program is to significantly reduce energy consumption at expeditionary bases and sites. The reductions would be obtained through the implementation of materiel and non-materiel energy solutions. TROPEC is a joint

interagency effort led by U.S. PACOM and supported by a team of military and energy experts from Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), Space and Naval Warfare Systems Center Pacific (SSC PAC) and the Naval Facilities Engineering Command Engineering and Expeditionary Warfare Center (EXWC).

2 Test Objectives

2.1 Emissions

Emissions of concern from waste burning typically include particulate matter (PM), mercury, volatile organic compounds (VOCs), polyaromatic hydrocarbons (PAHs), and polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs). VOCs include a range of compounds that can cause short or long term health effects. The majority of the compounds on the U.S. EPA's list of hazardous air pollutants (HAPs) are VOCs [1]. PCDDs/PCDFs are of interest due to their health effects at very low concentrations including immunotoxicity, carcinogenicity, and teratogenicity. PM_{2.5} (PM with an aerodynamic diameter less than or equal to 2.5 µm) is a criteria pollutant regulated by the U.S. EPA due to its health effects. When inhaled, PM_{2.5} can enter the lungs, potentially carrying metals and other toxic pollutants, which can cause adverse health effects.

Current regulations for Other Solid Waste Incinerators (OSWIs) under 40 CFR part 60 call for conducting emissions tests [2]. The required sampling methods often require multi-hour sampling under the assumption of steady state operating conditions resulting from continuous, relatively high mass throughput feed rates, such as from a continuously operating large waste processing facility. These methods may have limited utility in characterizing emissions from units that operate in a cyclic, non-steady fashion with small fuel batches and subsequent time-related emissions. This project attempted to characterize the emissions resulting from the batch to batch operation of the MAGS unit. Where possible, emissions samples were taken on a continuous basis to provide a time course of the emissions record throughout the MAGS' cycle of charging, gasification, and post-combustion. In cases where the analyte concentration or method was insufficient to allow for continuous measurement, batch samples ("integrated run") were collected to characterize the system's performance. To allow comparison of emissions between waste types, batch samples were taken in a consistent fashion by commencing and terminating samples at the same period in the charging and operation cycle.

Four different waste mixtures were tested in the MAGS for their ability to be processed and their resulting environmental emissions/residues. These mixtures were the responsibility of the DOD co-participants.

2.2 Ash and Scrubber Water

Six scrubber water and solid ash residue samples were collected to obtain a preliminary characterization of these effluents/residues. Ash and scrubber water samples were collected by the EPA team under the guidance of the equipment operators.

3 Experimental Approach

3.1 The MAGS technology

MAGS consists of two waste processing drums, or gasifiers, mounted inside a 20 foot (6.1 m) CONEX container and operating from a side and rear opening (Figure 3-1). Each waste processing drum is constructed with a thermally insulated heat exchange section that allows for the indirect heating of the waste by the exhaust gases from the combustion chamber. Waste is loaded into the primary reactor in batch mode and heated to approximately 1,400 °F. A controlled amount of pre-heated air is fed into the drum and brought into contact with the waste. The oxygen (O₂) in the air reacts with the waste to convert the organic molecules to a synthesis gas, or syngas, composed primarily of carbon monoxide (CO) and hydrogen (H₂). The syngas then passes into the combustion chamber where it is ignited to power downstream processes.

The combustion chamber is a thermally insulated reactor, maintained at approximately 2,000 °F (approximately 1,100 °C) through the combustion of diesel (during start up and stand by modes) and/or syngas. The system allows for heating of the combustion chamber during startup, as well as the ignition of the syngas. The hot exhaust gases from the combustion chamber serve as the heat source for the primary reactor. Oxygen concentration is monitored at the stack output and the air intake to the combustion chamber is regulated to maintain the desired oxygen (O₂) concentration. The gas flowrate through the MAGS system varies as a function of the production rate of combustible gas from the gasifier unit. The flow rate varies up to 250 standard cubic feet per minute (scfm) (7 standard m³/min). Exhaust gases leaving the heat exchange section are quenched with water to a temperature of approximately 180 °F and then are cleaned in a caustic (NaOH) scrubber to remove, acid gases and moisture prior to discharge.

The process comes to completion when all of the organic waste is fully gasified and the production of synthesis gas stops. The residue, which is believed to be mostly inorganic carbon in the form of ash, may contain any incidental metal and glass found in the original waste. The ash residue is recovered as a sterilized inert material that can be disposed.

A 6-inch (0.15 m) diameter flexible duct was attached to the stack to bring the exhaust gas down to a 6-inch (0.15 m) diameter straight pipe exhaust manifold oriented parallel to the ground, providing multiple port locations for probe access.

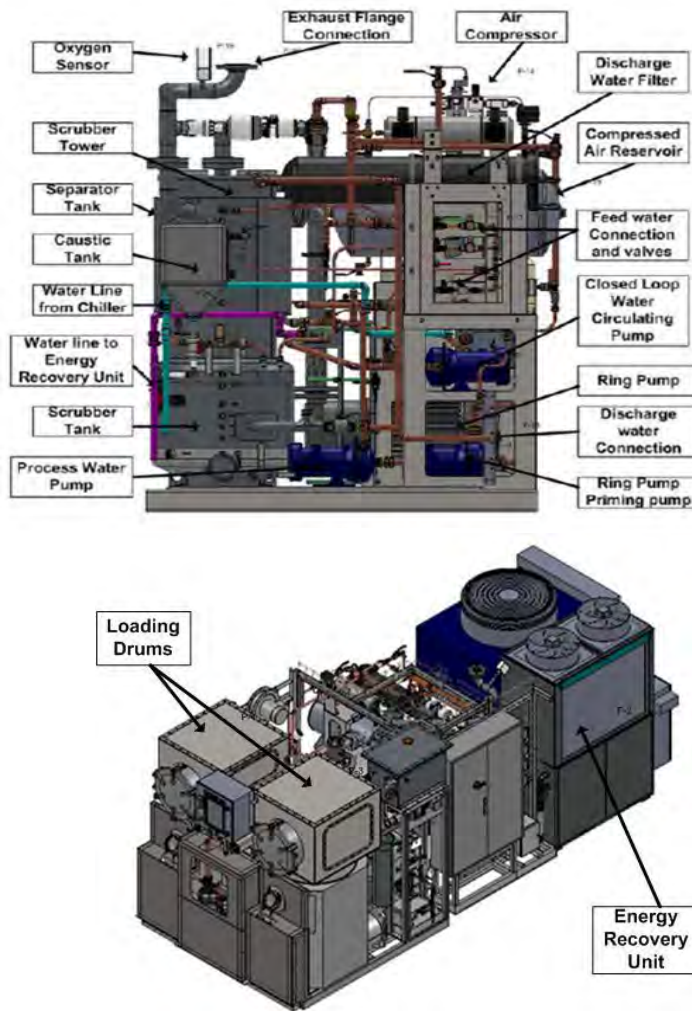


Figure 3-1. Schematic of MAGS technology.

3.2 Waste Composition and Carbon Fraction in the Waste

3.2.1 Waste Composition

The waste compositions used for the MAGS emissions analysis testing were developed from materials representative of waste stream compositions for deployed forces at small and extra small base camps. Base camp sizes and corresponding populations are outlined in a DOD joint force publication [3] (see Table 3-1). An additional waste source was a KMC waste dumpster. The U.S. Army Research Laboratory (ARL) conducted a historical review of DOD waste characterizations to identify standard material composition and waste generation characteristics representative of waste streams found at small and extra small base camps [4]. A subsequent study from ARL established a standardized waste recipe composition by waste category and corresponding percentage of respective material (Table 3-2); the study also proposed four

additional challenge recipes for cardboard/paper (not shown), food (not shown), plastic (Table 3-2), and wood (not shown) to further study the effect of waste source variation on system performance. The waste category “Plastic” is further divided by plastic type, #1-7 (see Table 3-3). At the time of the MAGS test, the ARL standard waste recipe report was in “draft” form and unpublished. The four recipes tested and their notation used here were a standard recipe (standard waste, SW), a plastic challenge recipe (high plastic, HP), a waste recipe collected from the KMC dumpster, and a First Strike Ration (FSR) recipe.

The Standard Waste and Plastic Challenge recipes were constructed as outlined in Table 3-2 and Table 3-3. The FSR recipe was a variation of the SW recipe, including food materials individually packaged for field use, rather than commercially available kibble dog food, used here as a food surrogate. The KMC recipe was constructed in a manner different from the other three recipes. The maintenance and cleaning staff at KMC filled a small dumpster with black trash bags from various places such as, rooms, kitchen, and recreation areas. Twenty bags were randomly selected from the dumpster and each bag was opened and characterized by waste categories identical to those used for the other three waste recipes. The results are shown in Table 3-2 and Table 3-3. The waste was re-bagged as found in the dumpster and staged for gasification.

Table 3-1. Base camp sizes and population ranges [3].

Base Camp Size	Population
Extra Small	50 – 299
Small	300 – 1,999
Medium	2,000 – 5,999
Large	6,000 or greater

Table 3-2. Standard and challenge recipes by weight percent. Standard and plastic recipe data from Margolin et al. [4].

Waste Category	Standard	Challenge Recipe		
	Recipe (SW)	Plastic (HP)	FSR	KMC
Cardboard	15%	10%	12%	16%
Mixed paper	10%	6%	7.7%	18%
Food waste	32%	21%	43%	44%
Plastic ^a	15%	44%	19%	12%
Wood	14%	9%	11%	0.09%
Metals ^b	6%	4%	2.5%	2.9%
Glass	1%	1%	0.8%	3.7%
Rubber and neoprene	1%	1%	0.8%	1.2%
Textile	3%	2%	2.3%	0.25%
Miscellaneous Waste/Other	3%	2%	2.3%	1.8%
Total	100%	100%	100%	100%

^a Plastic breakdown in Table 3-3. ^b 60% iron, 36% aluminum, and 4% other metals.

Table 3-3. Breakout of waste recipes by weight percent. Standard and plastic recipe data from Margolin et al. [4].

Plastic Category	Standard	Challenge Recipe		
	Recipe (SW)	Plastic (HP)	FSR	KMC
Plastic (Total)	15%	44%	19%	12%
#1 Polyethylene terephthalate (PET)	6.0%	18%	4.6%	1.1%
#2 High density polyethylene (HDPE)	2.7%	7.8%	2.1%	2.5%
#3 Polyvinyl chloride (PVC)	0.9%	2.6%	0.7%	0.00%
#4 Low density polyethylene (LDPE)	2.7%	7.8%	2.1%	3.8%
#5 Polypropylene (PP)	0.3%	0.8%	0.2%	0.93%
#6 Polystyrene (PS)	1.8%	5.4%	1.4%	2.8%
#7 Other (e.g., polycarbonate, acrylic, nylon, bioplastics, composites)	0.6%	1.6%	7.9%	0.68%

New materials were purchased by category type to build identical waste bags that were fed into the MAGS. Glass bottles, rubber mulch, plastic bottles, and cardboard are a few examples of purchased materials. Testing time for each recipe was determined to be at least four hours to minimize the chance of analyte non-detects. A four hour run time was estimated to require 16 bags of waste per recipe. Therefore, 16 identical bags were created for each individual test (i.e., 16 bags for triplicate testing on the standard waste required 48 bags total, see Figure 3-2).



Figure 3-2. Standard waste bags being constructed.

Variation from the SW recipe included packaging waste from four FSRs per waste bag, 5.8 lb (2.6 kg) of FSR food per waste bag, and packaging cardboard from seven FSR cases (distributed evenly across all bags). No plastics were removed to adjust for the additional material from the FSR food packaging (the additional weight per FSR was 0.43 lb/0.20 kg). FSR food was used as the food waste component instead of dog food, oil, and water (water required per the SW recipe was included in addition to the FSR food). FSR packaging cardboard generated from

unpacking the FSR food was included in the waste bags. Cardboard from the SW recipe was adjusted to account for the additional cardboard from the FSR cases. The aluminum cans were also removed from the FSR tests due to concerns that the previous tests with cans led to system jams. All other waste categories for the FSR recipe were held constant to the standard recipe.

Historical DOD waste characterizations have revealed that small and extra small base camps generate waste rates of approximately 4.5 lb per person per day (lbs/person/day) (2.0 kg per person per day). This weight was used to determine the number of FSRs to include in the FSR waste recipe, based on 288 lb (131 kg) of waste. Each bag was constructed to weigh 18 lb (8.2 kg). Weight, as well as bag volume, was a factor in ensuring that the bags could be fed into each of the MAGS chambers. Bags were filled with materials from each category as a corresponding percentage of 18 lb (8.2 kg). For example, the standard recipe requires 14% wood, thus 2.52 lb (1.1 kg) of wood were included in each bag of the standard recipe.

$$\frac{18 \text{ lb}}{\text{bag}} * \frac{16 \text{ bags}}{\text{recipe}} = 288 \text{ lb/recipe} \quad \text{Equation 3-1}$$

$$\frac{288 \text{ lb/recipe}}{4.5 \text{ lb per person and day}} = 64 \text{ people per recipe} \quad \text{Equation 3-2}$$

Equation 3-1 and Equation 3-2 show how 288 lb (131 kg) represents waste generated by 64 service members. Each FSR case contains nine meals and one FSR is designed to support 1 person for 24 hours. Therefore, 64 FSRs were deconstructed per FSR test. The food was removed from the packaging, see Figure 3-3.



Figure 3-3. Deconstructing FSRs.

3.2.2 Carbon Fraction in the Waste

The carbon mass balance approach was used to calculate emissions factors in unit pollutant per unit waste (Equation 3-3). This approach assumes that all carbon in the waste is emitted as carbondioxide (CO₂), carbon monoxide (CO), and methane (CH₄).

$$\text{Emission Factor (g Pollutant/g waste)} = F_c \times \frac{\text{Pollutant } \left(\frac{mg}{m^3}\right)}{\sum \text{Carbon } \left(\frac{mg}{m^3}\right)} \quad \text{Equation 3-3}$$

where F_c = carbon fraction in the waste, and Carbon = amount of carbon sampled derived from CO₂, CO and CH₄ concentration in the stack.

The total carbon fraction of each waste recipe was calculated using carbon fractions from Liu and Lipták [5], Table 3-4.

Table 3-4. Carbon fraction of each waste recipe.

Waste Category	Carbon Fraction in Material ^a	Standard	Challenge Recipe		
		Recipe	Plastic	FSR	KMC
		(SW)	(HP)		
Carbon Fraction from each Waste Category ^b					
Cardboard	0.44	0.066	0.044	0.050	0.069
Mixed paper	0.44	0.044	0.026	0.034	0.077
Food waste	0.49, 0.76 ^c	0.048	0.031	0.21	0.21
Plastic	0.74	0.11	0.33	0.14	0.087
Wood	0.50	0.071	0.045	0.054	4.5E-04
Metals	0.0076	4.6E-04	3.0E-04	1.9E-04	2.2E-04
Glass	0.0056	5.6E-05	5.6E-05	4.5E-04	0
Rubber and neoprene	0.74	0.0074	0.0074	0.0059	0.0091
Textile	0.55	0.017	0.011	0.015	0.0014
Miscellaneous Waste/Other	0.0076-0.74	0.018	0.012	0.017	0.0089
Total		0.38	0.50	0.52	0.47

^a Data from Liu and Lipták [5]. ^b Carbon fraction in material × waste fraction in recipe ^c Carbon fraction for cooking oil.

3.3 Sample Type Definition and Location

The target pollutants and their sampling methods are described in Table 3-5. The target emissions were collected from a fabricated exhaust pipe extension (see Figure 3-4), which was connected to the Exhaust Flange Connection (see Figure 3-1). This fabricated section provided sampling ports for the sampling probes, increased the duct cross section to minimize wall effects on sampling, and created sufficient length from bends and sampling ports to flow disturbances on subsequent ports.

Table 3-5. Target pollutants and sampling methods.

Pollutant	Instrument/Method(s)	Duration
Total PM	SW-846 Method 0010 [6]	Integrated run, 0-4h
PCDD/PCDF, PAH	SW-846 Method 0010 [6], U.S. EPA Method 23[7]/HRGC/HRMS ^a , U.S. EPA Method 8270D [8]/HRGC/LRMS ^b	Integrated run, 0-4h
VOCs, CO ₂ , CO, CH ₄	SUMMA Canister/U.S. EPA Method TO-15 [9]/U.S. EPA Method 25C [10]	Integrated run, 12 min and 2h samples
NO _x , O ₂ , CO, CO ₂ , SO ₂ , CH ₄ , HCl	FTIR ^c - Gasmeter DX-4000, U.S. EPA Method 320 [11], 321 [12]	Real time
CO ₂	LI-COR 820, Method 3A calibration	Real time
Metal: Mercury	Sorbent trap/U.S. EPA Method 30B [13]	Integrated run, 0-4 h
PM mass and size	Dilution + Teflon filters/ Modified U.S. EPA Method 5[14]/gravimetric [15]	Integrated run, 0-4 h
Metals: Cd, Pb, others	Dilution + Teflon filters/gravimetric and ICP ^d [16] and XRF ^e [17]/Compendium	Integrated run, 0-4 h
PM mass and size	Dilution + DustTrak DRX (PM ₁ , PM _{2.5} , PM ₄ , PM ₁₀ and Total PM)	Real time
Black Carbon	Dilution + AE51/optical	Real time, 2 filter tickets per 0-4 h

^aHigh resolution mass spectrometry. ^bLow resolution mass spectrometry. ^cFourier transform infrared. ^dInductively coupled plasma. ^eX-ray fluorescence.

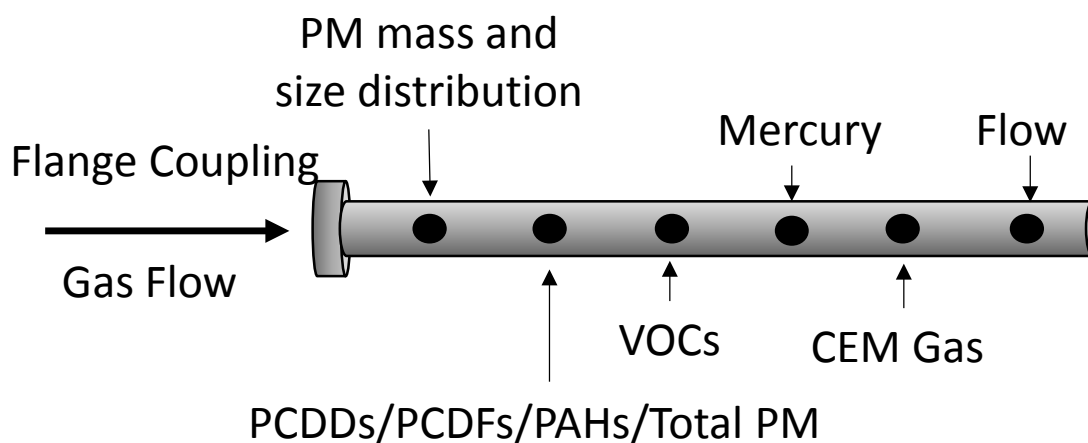


Figure 3-4. Sampling ports and order for each pollutant sampled. Not to scale.

3.4 Test Matrix and Daily Testing Procedure

3.4.1 Test Matrix

Eight tests using four different waste type compositions were conducted in a seven-day period. Triplicate runs were conducted for the standard waste (SW) composition, duplicate runs were performed for high plastic (HP) and FSR waste compositions, and one run was performed for the KMC waste (Table 3-6). While test randomization was preferred, delayed receipt of some materials and the overall time/cost constraints of the project prevented true randomization. Between each test (except 7/13/2015), the system was cooled down and the chamber cleaned to minimize any potential test against test carryover effects.

Table 3-6. Test Matrix.

Date	Waste	PAHs	PCDDs/ PCDFs	PM	VOCs	Mercury	Metals	PM by size	CEM
07/10/2015	Standard Waste (SW-1)	x	x	x	x	x (2)	W	W	O ₂
07/11/2015	Standard Waste (SW-2)	x	x	x	x	x (2)	X	x	x
07/12/2015	Standard Waste (SW-3)	x	x	x	x (5)	x (2)	X	x	x
07/13/2015	High Plastic (HP-1)	x	x	x	x	x (2)	X	x	x
07/13/2015	High Plastic (HP-2)	x	x	x	x	x (2)	X	x	x
07/14/2015	KMC Waste (KMC)	x	x	x	x	x (2)	X	x	x
07/15/2015	FSR Waste (FSR-1)	x	x	x	x	x (2)	X	W	x
07/16/2015	FSR Waste (FSR-2)	x	x	x	x	x (2)	X	W	x

x = one sample if nothing else mentioned. O₂ = only oxygen measured. W = sampling terminated due to water saturation in the sampler.

3.4.2 Daily Testing Procedure

The daily procedure for the MAGs unit started with a four hour pre-heat period burning diesel fuel (Figure 3-5). Emissions sampling started when the first waste bag was loaded into the MAGS. Gasification was accompanied by co-combustion with diesel fuel for the first few waste loads as determined by the oxygen sensor. Scrubber water was collected for 6 of 7 days at the end of the day's run. Ash was collected in the morning after the overnight cool down.

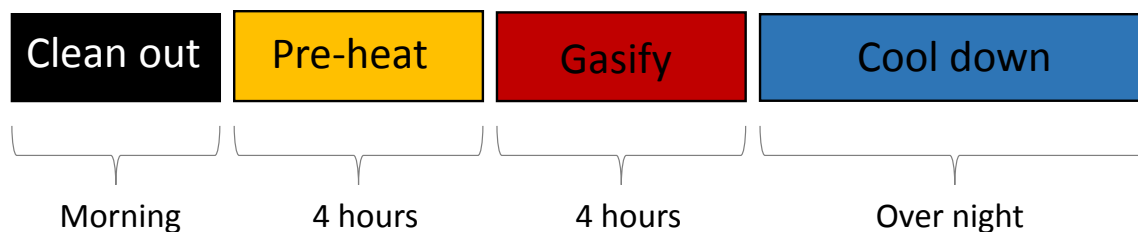


Figure 3-5. The daily testing procedure.

4 Sampling Procedures

The conventional extractive sampling techniques are based on established U.S. EPA Methods, or their modified versions, adapted to this particular MAGS source, and for a cyclically operating unit.

4.1 Instrument/Equipment Testing, Inspection, and Maintenance

Sampling system preventive maintenance was performed prior to the start of each daily test for each waste source. Daily calibration of the continuous emission monitor (CEM) ensured continued reliable operation. Prior to the start of the sampling program, the EPA Metrology Laboratory calibrated field sampling equipment, such as the SW-846 Method 0010 meter boxes.

4.2 PCDD/PCDF and PAH Sampling

4.2.1 Train

PCDDs/PCDFs were sampled via Modified U.S. EPA Method 23 [7] using a SW-846 Method 0010 [6] sampling train (Figure 4-1). PAH compounds were taken from a portion of the extract from the PCDD/PCDF train. The method modifications included pre-spiking of the XAD-2 (adsorbent styrene divinylbenzene polymer) traps with carbon-13 labeled PCDDs/PCDFs and deuterated PAHs, pre-sampling surrogates. The sampling trains consist mainly of a heated probe, heated box containing a filter, water-cooled condenser, water-cooled XAD-2 cartridge, impinger train for water determination, leak-free vacuum line, vacuum pump, and dry gas and orifice meters with flow control valves and vacuum gauge. Temperatures were measured and recorded in the hot filter box (set at 257 °F/125 °C), at the impinger train outlet, at the XAD-2 cartridge outlet (maintained below ambient temperature) and at the inlet and outlet of the dry gas meter. Leak checks were conducted at the beginning and end of each sample run. Prior to sampling, all glassware, probe, glass wool and aluminum foil were cleaned following the U.S. EPA Method 23 [7] cleaning procedure.

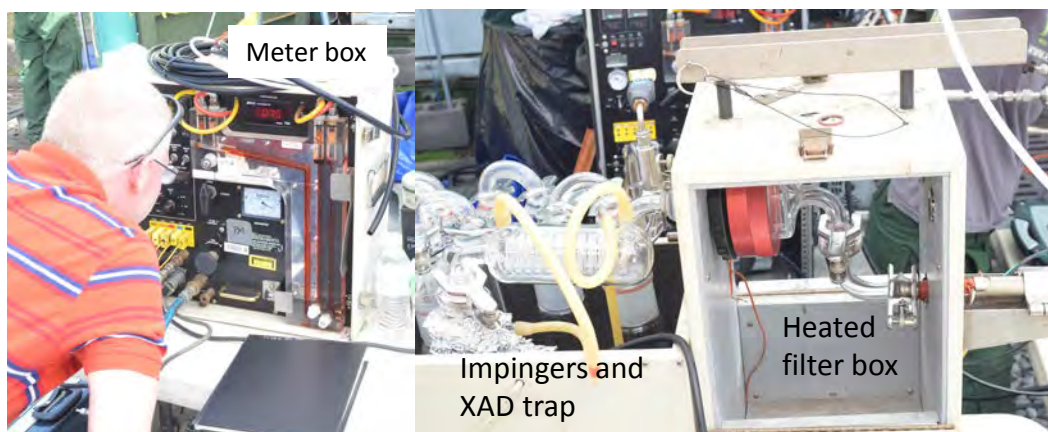


Figure 4-1. PCDD/PCDF, PAH and PM sampling train.

4.2.2 Recovery

Following completion of each test run, the sampling train was recovered as soon as the probe was removed from the duct. During the transportation between the test facility and the designated sample recovery area, openings of the impinger assembly were sealed with aluminum foil or ground glass caps. The organic rinses of the train were performed as specified in U.S. EPA Method 23 [7] and U.S. EPA Method 0010 [6] but modified to eliminate inter-method solvent contradictions.

4.2.3 Analyses

The target compounds was performed by the U.S. EPA (in-house, at the EPA Research Triangle Park, NC, Campus). The extraction and cleanup procedures for the target PCDD/PCDF compounds of interest followed U.S. EPA Method 23 [7] with some analytical modifications. A group of carbon-labeled PCDDs/PCDFs was added to the XAD-2 trap before sample collection. Another group of 14 carbon-labeled PCDD and PCDF internal standards, representing the tetra-through octachlorinated homologs, was added to every sample prior to extraction. The role of the internal standards is to allow quantification (via the internal standard methodology) of the native PCDDs and PCDFs in the sample as well as to determine the overall method efficiency. The surrogate recoveries were measured relative to the internal standards and are a measure of the sampling train collection efficiency. The standards used for chlorinated dioxin/furan identification and quantification were a mixture of standards containing tetra- to octa-PCDD/PCDF native and ¹³C-labeled congeners designed for Modified U.S. EPA Method 23 (ED-2521, EDF-4137A, EDF-4136A, EF-4134, ED-4135, CIL Cambridge Isotope Laboratories Inc., U.S.A.). The PCDD/PCDF calibration solutions were prepared in-house and contained native PCDD/PCDF congeners at concentrations from 0.5 ng/mL to 20 ng/mL.

Initial concentration steps were performed using a three-ball Snyder column. The XAD-2 was extracted first with dichloromethane, then with toluene, resulting in two solvent extracts. Each of these extracts was divided in half and combined with the other extract-half to create two extract mixtures. One of the extract mixtures was concentrated and solvent-exchanged into hexane. The hexane extract was cleaned by a Fluid Management Systems (FMS) for PCDD/PCDF analysis. A keeper solvent (decane) was used after extract cleanup by FMS. PCDD/PCDF analysis was performed using a HRGC/HRMS. All of the PCDD/PCDF extraction surrogate standard recoveries were 61-101%, within the acceptance criteria of the method (between 25 and 130%). The PeCDF/HxCDF/HxCDD/HpCDF pre-sampling standard recoveries were 82-100%, within the acceptance criteria. The TeCDD pre-sampling surrogate recovery standard was satisfied for all samples except the trip blank which fell outside the acceptance criteria. This failure was found to be due to co-elution of the standard with a planar PCB congener with the same ion and retention time as the TeCDD surrogate congener. The pre-sampling spike is not used for quantification but serves as a quality assurance check for the sampling stage.

PAH analysis was conducted from a portion of the remaining extract mixture in accordance with SW-846 Method 8290A [18]. PAH analysis was performed using HRGC/LRMS. All but one of the PAH surrogate standard recoveries, 66-128%, were within the acceptance criteria of the method (between 25 and 130%). The SW-1 test had one of three PAH pre-sampling surrogate standards

that was outside the acceptance criteria (at 266%) due to co-elution of an unknown compound with the same retention time and ion. The pre-sampling spike was not used for quantification but served as a quality assurance check for the sampling stage. The PCDD/PCDF/PAH trip blank showed no detectable levels of any PCDDs/PCDFs/PAHs analyzed.

4.2.4 Toxicity equivalence value

PCDDs and PCDFs include 75 and 135 congeners, respectively. Of these 210 congeners, 17 are toxic and have been assigned Toxic Equivalency Factor (TEF) values [19] (Table 4-1), with the most toxic value being unity. The toxicity equivalence (TEQ) value is obtained by multiplying the concentration of a PCDD/PCDF congener by its TEF-value and summing the result for all 17 toxic congeners. The U.S. EPA has listed 16 priority PAHs. Some of these PAHs are probably carcinogenic to humans according to U.S. EPA. Table 4-2 lists these 16 PAHs and their TEFs for humans.

Table 4-1. PCDD/PCDF Toxic Equivalent Factors for mammals [19].

PCDDs	TEF	PCDFs	TEF
2,3,7,8 – TCDD	1	2,3,7,8 - TCDF	0.1
1,2,3,7,8 – PeCDD	1	1,2,3,7,8 - PeCDF	0.03
1,2,3,4,7,8 - HxCDD	0.1	2,3,4,7,8 - PeCDF	0.3
1,2,3,6,7,8 - HxCDD	0.1	1,2,3,4,7,8 - HxCDF	0.1
1,2,3,7,8,9 - HxCDD	0.1	1,2,3,6,7,8 - HxCDF	0.1
1,2,3,4,6,7,8 - HpCDD	0.01	1,2,3,7,8,9 - HxCDF	0.1
1,2,3,4,6,7,8,9 - OCDD	0.0003	2,3,4,6,7,8 - HxCDF	0.1
		1,2,3,4,6,7,8 - HpCDF	0.01
		1,2,3,4,7,8,9 - HpCDF	0.01
		1,2,3,4,6,7,8,9 - OCDF	0.0003

Table 4-2. PAH Toxic Equivalent Factors for humans [20].

Compound	TEF	Compound	TEF
Naphthalene	0	Benzo(a)anthracene ^{a,b}	0.005
Acenaphthylene	0	Chrysene ^{a,d}	0.03
Acenaphthene	0	Benzo(b)fluoranthene ^a	0.1
Fluorene ^{c,d}	0	Benzo(k)fluoranthene ^{a,b}	0.05
Phenanthrene ^{c,d}	0.0005	Benzo(a)pyrene ^{a,b}	1.0
Anthracene ^{c,d}	0.0005	Indeno(1,2,3-cd)pyrene ^{a,b}	0.1
Fluoranthene ^{c,d}	0.05	Dibenz(a,h)anthracene ^a	1.1
Pyrene ^{c,d}	0.001	Benzo(ghi)perylene ^{c,d}	0.02

^a Probably carcinogenic to humans, according to U.S. EPA. ^b Probably and possibly carcinogenic to humans, according to International Agency for Research on Cancer (IARC). ^c Not classifiable as carcinogenic to humans, according to U.S. EPA. ^d Not classifiable as carcinogenic to humans, according to IARC.

4.3 Particulate Matter

4.3.1 *Total PM*

4.3.1.1 *Train*

Total PM was sampled according to modified U.S. EPA Method 5 [14], using the same PM filter as in the U.S. EPA Method 23 [7] train. Each of these filters was pre-weighed at U.S. EPA before shipment and stored in tape-sealed glass Petri dishes.

4.3.1.2 *Analyses*

The filters underwent a 24-hour desiccation before the first tare and gross weighing (pre and post-sampling). The filters were returned to the desiccator for an additional six hours before the second weighing. If the 24-hour and six-hour weighings agree to within 0.5 mg, the filter weight was accepted. The six-hour desiccation/weighing cycles were repeated until the two weights agreed to within 0.5 mg. The balance is calibrated yearly by the EPA Meteorology Laboratory with National Institute of Standards and Technology (NIST) certified weights.

4.3.2 *PM Mass and Size Distribution*

4.3.2.1 *Dilution system*

Samples for PM emissions evaluation were extracted from the duct with an eductor supplied with ultra-high purity air from a compressed gas cylinder (Airgas, Hilo, HI, USA). Isokinetic conditions were not achieved continuously as the flow in the duct was variable. The eductor was equipped with a stainless steel (SS) orifice to restrict the sample flow and ensure sufficient dilution. Dilution was necessary to reduce the water vapor and sample temperature into a range suitable for PM measurement (i.e. <95% Relative Humidity (RH) and Temperature < 95 °F/35°C). The amount of dilution necessary was dependent upon the humidity in the exhaust. The diluted sample was transported from the duct by stainless steel tubing and anti-static tubing to minimize losses of particle to the walls, and divided among the PM measurements with an aerosol flow splitter. Instruments extracted the PM sample under positive pressure from the manifold to evaluate particulate emissions with a modified U.S. EPA Method 5 filter sample and real time measures of PM mass with a DustTrak DRX Model 8533 (TSI Inc., MN, USA) and black carbon (BC) with an AE-51 (Aethlabs, Berkeley, CA, USA). The dilution ratio for the PM measurements was determined by measuring the amount of CO₂ (LI-COR 820, Biosciences, USA) in the diluted stream and compared with the CO₂ (Gasmeter DX-4000, Finland) measured in the exhaust duct (see Chapter 4.7). Dilution was controlled primarily through selection of an appropriate orifice, though some control was afforded through control of the supplied pressure of the dilution air.

4.3.2.2 *Filterable Particulate Matter Measurements*

Filterable particulate matter sampling was performed according to a modified EPA Method 5 - Determination of Particulate Emissions from Stationary Sources, as described in 40 CFR Part 60, Appendix A with respect to volume measurement for both PM determinations. A diluted

sample was extracted from the PM manifold through a pre-weighed 47-mm, 2 micron pore size Teflon filter held in a stainless steel sample holder. Dilution prevented condensation. The gas volume was measured by a dry gas meter followed by an orifice used for flow control. Gravimetric analysis of the filters pre- and post-sampling was performed by Chester Lab Net following the procedures in 40 CFR Part 50 [15].

4.3.2.3 On-line PM Instrumentation

Black carbon and continuous PM mass were measured with on-line instrumentation (AE-51 and DustTrak DRX) following the manufacturer's instructions. The AE-51 Aethalometer (Aethlabs, Berkeley, CA, USA) is an instrument that provides real-time measurement of black carbon concentration in the exhaust. Black carbon, or "soot", is generated during combustion and is emitted from all types of combustion. The microaethalometer determines the amount of BC through a calibrated measure of the amount of optical attenuation through a filter loaded with particles.

Continuous PM - TSI DustTrak DRX Model 8533 (TSI Inc., MN, USA). This instrument measures light scattering by aerosols as they intercept a laser diode and has the capability of simultaneous real time measurement (every second) of PM₁, PM_{2.5}, Respirable (PM₄), PM₁₀ and Total PM (up to 15 µm). The aerosol concentration range for the DustTrak DRX is 0.001-150 mg/m³ with a resolution of ±0.1% of reading. Concurrently, an enclosed, 37-mm pre-weighed filter cassette provides a simultaneous Total PM gravimetric sample. The enclosed gravimetric sample was used to conduct a custom photometric calibration factor (PCF). The DustTrak DRX is factory calibrated to the respirable fraction, with a PCF value of 1.00. A custom PCF is conducted as per manufacturer's recommendations for PM using the simultaneously sampled PM by filter concentration divided by PM by filter mass concentration. This factor was applied to scale the real time data. A zero calibration was performed before each day using a zero filter, and a flow calibration was performed before each day with a Gilibrator flowmeter, following procedures in Operation and Service Manual Model 8533/8534 (P/N 6001898, Revision F, January 2011).

4.4 Metals

4.4.1 Metals by inductively coupled plasma spectroscopy and X-ray Fluorescence Spectrometry

The 47-mm PM Teflon filters were analyzed for metals such as iron (Fe), copper (Cu), cadmium (Cd) and Lead (Pb) by ICP and XRF by Chester Lab Net following the procedures described in U.S. EPA Compendium Methods IO 3.4 [16] and 3.3 [17], respectively. The standard reference materials used for the quality assurance (QA)/control (QC) had a recovery of 93.5-109.2%.

4.4.2 Mercury

4.4.2.1 Train

Sorbent tubes were used for sampling of mercury (Hg) emissions in accordance with U.S. EPA Method 30B [13], allowing for a cumulative sample over the course of a multi-batch run. The tubes were analyzed individually. The measured Hg mass was related to the respective gaseous sample volume and the resulting Hg mass/volume (µg/m³) concentrations were compared, and

the degree of agreement was used to validate the measurement. A field recovery test was performed with each duplicate sample where an additional trap was statically spiked with a known amount of elemental mercury (Hg^0), sampled, and the recovered amount was used to validate the quantitative accuracy of the measurement.

4.4.2.2 Analyses

Analysis of the sorbent tube samples were accomplished using an Ohio Lumex thermal decomposition furnace (Model M-324) (Solon, Ohio) and a Zeeman-effect atomic absorption spectrometer analyzer (Model RA-915+, Ohio Lumex). Calibrations were performed NIST traceable Hg chloride standards. The instrument was calibrated daily using 5 to 100 ng of Hg and the criteria listed in U.S. EPA Method 30B [13]. Sorbent tubes were analyzed by transferring the sorbent into quartz combustion boats for analysis. A thin layer of sodium carbon was used to cover the activated carbon, the combustion boat was then inserted into the decomposition furnace, operated at 775 °C, and the Hg was reduced to elemental Hg and detected by the photospectrometer. Flow through the decomposition furnace was operated at 1 L/min and controlled using a mass flow meter. This analysis technique has a derived method detection limit (MDL) of 0.21 ng per tube section.

The majority of the data reduction procedures are detailed in U.S. EPA Method 30B [13] and Method 5 [14]. The Lumex RA-915+ thermal decomposition Hg analyzer was used to analyze the carbon tubes. The data analysis software package developed for the Lumex was used to measure the peak area of the Hg signal as the Hg was reduced and detected by the analyzer. These data were transferred to Excel to calculate a linear calibration curve of the form $Y = mX + b$ where Y is the mass Hg (in ng) and X is the area count from the software. A linear curve fit was applied to the average instrument response for each standard.

Mercury concentrations as determined through U.S. EPA Method 30B [13] have units of $\mu\text{g}/\text{dry standard cubic meter (dscm)}$ corrected for gas dilutions. The recovery for the analytical bias test was 102%, which is within the acceptance criteria of 90-110%. The recovery for the field recovery test was 98%, which is within the acceptance criteria of 85-115%.

4.5 Volatile Organic Compounds

4.5.1 Sampling Method

VOCs were sampled via U.S. EPA Method TO-15 [9] using 6 L SUMMA canisters (Figure 4-2) supplied by the analytical laboratory (ALS, Simi Valley, CA, USA). Sampling occurred for approximately 120 min in duration for each test as well as four 10-20 min samples throughout one standard waste test (Test SW-3, 7/12/2015). Sampling was initiated upon waste introduction to the gasifier and terminated when the canister was 90% full, leaving enough volume for addition of diluent gas to prevent condensation. The four sequential SUMMA canisters were used to characterize the VOC emissions from the period following introduction of a waste batch to characterize the temporal profile of emissions during waste gasification/combustion. Following the end of each period of canister sampling, the manual valve was closed, the metal filter and pressure gauge were removed, and the canister was

returned to its shipping container. SUMMA canisters were shipped to and from the field in boxes as per the ALS California laboratory instructions. The SUMMA canister samples were analyzed for VOCs within 12-18 days of collection.



Figure 4-2. VOC collection using SUMMA Canister.

4.5.2 Analyses

The SUMMA canisters were analyzed by ALS California using U.S. EPA Method TO-15 [9] using a gas chromatograph-low resolution mass spectrometer (GC/LRMS) in full scan mode. The VOC surrogate recoveries for all but one of the collected samples were 99-108%, which is within the acceptance criteria of the method (70-130%). The third 12 min sample had one of the three surrogate recoveries at 139%, which is slightly above the acceptance criteria. The other two surrogate recoveries (97 and 103%) for the same sample were within the acceptance criteria.

To calculate emissions factors, CO, CO₂, and CH₄ in the SUMMA canisters were analyzed by gas chromatography using flame ionization detection/total combustion analysis according to Modified U.S. EPA Method 25C [10]. The CO₂ recovery was 93% and CO and CH₄ recoveries were 99% and 100%, which are within the acceptance criteria of 72-128% and 86-124%, respectively.

The canisters were cleaned by ALS prior to sampling to the method reporting limit (MRL) such that any values below MRL may be biased high due to residual carryover.

4.6 Flue gas Volumetric Flow Rate and Temperature

A flexible duct conveyed the combustion gases from the exhaust flange connection (see Figure 3-1). The 20 ft (6.1 m) long, 6 in. (15 cm) diameter, stainless steel sampling duct allowed multiple sampling ports to be accessed. U.S. EPA Method 1a [21] was used to determine the duct traverse points and to determine if turbulent flow was present in the sampling system. To allow for sampling beyond eight diameters downstream of a bend or flow disturbance, the first sampling point was 5 feet (60 inches, 1.5 m) from the flex duct connection to the straight sampling duct. The cross-sectional area of the duct was divided into a number of equal areas. Traverse points were then located within each of these equal areas. Due to the small duct diameter, 12 points (six in the vertical and six in the horizontal plane) were sampled using the criteria listed in U.S. EPA Method 1 (Table 4-3).

Table 4-3. Traverse points.

Traverse Point	% of Duct Diameter
1 and 7	4.4
2 and 8	14.7
3 and 9	29.5
4 and 10	70.5
5 and 11	85.3
6 and 12	95.6

U.S. EPA Method 2 [22] was used to measure the stack velocity using a pitot head differential device. A Shortridge Instruments (Scottsdale, AZ, USA) Airdata Multimeter was used to measure the differential pressure of the Airfoil pitot device. The Airdata Multimeter has a built in thermocouple and barometer for making measurements in actual cubic feet per minute (ACFM). A velocity head and temperature measurement ($\pm 1.5\%$ of the minimum stack temperature) were taken at each traverse point as determined in U.S. EPA Method 1 [21]. A static stack pressure measurement was taken and the barometric pressure was taken to within 2.54 mm mercury. The Airdata Multimeter was connected to a computer and logging software was used to continuously record the stack velocities at a single center point to monitor flows during sampling.

4.7 Continuous Emissions Monitoring

Several primary gaseous flue-gas constituents were analyzed continuously from port number 5 in the sampling manifold (Figure 3-4) using an FTIR Gas Analyzer (Gaset DX-4000, Finland) that includes monitors for CO, CO₂, O₂, THC, SO₂, HCl and (nitric oxide – nitrous oxide) NO-NO₂-NO_x. CO₂ was also continuously measured using a non-dispersive infrared (NDIR) LI-COR 820 instrument (LI-COR Biosciences, USA) in the diluted stream. The dilution ratio was determined by comparing the CO₂ concentration from the FTIR (in the stack) with the CO₂ concentration in the dilution system.

4.7.1 Gaset DX-4000

An FTIR gas analyzer has the capability of measuring both inorganic and organic species in complex matrices due to the specificity of the wavelength for the corresponding analyte. FTIR relies on the specific vibrational energy (wavelength) transitions of IR light being absorbed by the molecule. Molecules sensitive in the IR region generate a specific spectral plot with sharp peaks in various regions of the plot dependent on the molecule or the class of molecule. This molecular dependence allows the FTIR to measure multiple species of both organic and inorganic compounds simultaneously.

4.7.2 LI-COR 820

The LI-COR 820 (LI-COR, Lincoln, Nebraska, USA), was configured with a 5.5 inch (0.14 m) optical bench, giving it an analytical range of 0-20,000 ppm with an accuracy specification of less than

3% of reading. A particulate filter precedes the optical lens. The LI-COR 820 CO₂ concentration was recorded every second using the LI-COR 820 software (version 2.1) on a portable computer.

4.7.3 Calibration Procedure

The FTIR underwent daily multi-point calibration for CO₂, CO, O₂, NO_x, and SO₂ using modified U.S. EPA Methods 3A [23], 6C [24], and 7E [25] at the beginning of the test as well as a drift check at the end of each day (Table 4-4). Similarly, the LI-820 underwent multi-point calibration for CO₂ according to U.S. EPA Method 3A [23], as well as a check for drift at the end of the test day.

All gas cylinders used for calibration were certified by the suppliers that they are traceable to NIST standards. A precision gas divider Model 821S (Signal Instrument Co. Ltd., Surrey, England) was used to dilute the high-level span gases for acquiring the mid-point concentrations for the calibration curves. The precision gas divider was evaluated in the field as specified in U.S. EPA Method 205 [26].

Table 4-4. FTIR analyzer calibration error and drift data, as well as calibration curve fit.

Compound	Cylinder Value	ACE ^a (%)	Drift ^b (%)	r ² Calibration Curve ^c
CO ₂ (%)	14.92	2.3	1.6	0.9967
CO ₂ (%)	8.95	6.3		
CO ₂ (%)	2.98	0.18		
CO ₂ (%)	0	0		
CO (ppm)	150	11	-0.4	0.9996
CO (ppm)	90	-1.2		
CO (ppm)	30	-7.4		
CO (ppm)	0	-0.35		
SO ₂ (ppm)	15.2	-15	-11 ^d	0.994
SO ₂ (ppm)	9.12	-12		
SO ₂ (ppm)	3.04	-18		
SO ₂ (ppm)	0	-6.8		
NO (ppm)	150	3.8	0.6	0.9958
NO (ppm)	90	2.4		
NO (ppm)	30	-5.6		
NO (ppm)	0	0		
O ₂ (ppm)	15.0	10	-0.5	0.9999
O ₂ (ppm)	9.0	6.9		
O ₂ (ppm)	3.0	1.6		
O ₂ (ppm)	0	-0.09		

^a ACE analyzer calibration error in accordance with U.S. EPA Method 7E [25]. ^b Drift = ACE pre-tests – ACE post-tests, between first and last test day modified U.S. EPA Method 7E [25]. ^c r² = measure of determination, how good the instrument reading correlates with the actual cylinder concentration value. ^d Drift between each test day was less than 2.0%.

4.8 Solids and Water Sampling

Ash samples were conducted to gain a preliminary characterization of the metal composition. The gasifier ash was cleaned out on a daily basis by PACOM personnel after system cool down. The ash was divided up into coarse and fine fractions for weight determination. The daily ash fractions were combined, mixed, and coned and quartered as per instruction in AP-42, Appendix C.2 [27] for collection of samples for metal analyses. The ash was analyzed for metals by XRF (PANalytical PW2404, Westborough, MA) conducted at the U.S. EPA (in-house, at the EPA Research Triangle Park, NC Campus) following the procedures described in EPA/NRMRL SOP 5304.2. XRF results were corrected for the filter blank results and then recalculated to sum to a total of 100% of the collected PM mass. This normalization to 100% was done by assuming the elements were present as their oxides and that the balance of unmeasured mass was carbon.

Scrubber water was collected after each test day. The samples were each spiked with known quantities of three semi-volatile organic tracer compounds (nitrobenzene-d5, 2-fluorobiphenyl and terphenyl-d14) at 5 µg each and then extracted three times with methylene chloride. Each sample's extract was concentrated to 1 mL, and then 1 µL was injected into a gas chromatograph/mass spectrometer (GC/MS) for a 70 min run. The analysis was similar to a U.S. EPA SW-846 Method 8270 Tentatively Identified Compound (TIC) screen. The TIC screen uses a spiked compound (usually the internal standards from the targeted compound analysis) to allow a rough quantitation.

4.9 Moisture

Moisture content in the stack was sampled according to modified U.S. EPA Method 4 [28], using the U.S. EPA Method 23 [7] train (see Chapter 4.2.1). The moisture in the collected gas was condensed in pre-weighed impingers and quantified by post-sampling weights. The sampling volume was obtained from the meter box.

4.10 Data Precision

The data precision was checked by calculating:

- Relative percent difference (RPD) for any pair of duplicates

$$RPD = 100 \times \frac{Q-B}{Q+B} \quad \text{Equation 4-1}$$

where: Q = results from one sample, B = results from replicate samples

- Standard deviation (STDV) if more than duplicate measurements were conducted

$$STDV = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \mu)^2} \quad \text{Equation 4-2}$$

where: μ = average results from all samples, x_i = results from one sample, N = number of samples

Or expressed as coefficient of variation (CV) = $100 \times \text{STDV}/\text{Average}$

5 Results

Seven test days encompassed gasification of four waste types during eight tests. Data are presented by individual run results, like-run averages, and “Total” defined as the average of all samples together. Emissions are expressed as volumetric concentrations and emissions factors, the latter based both on the waste input schedule and the carbon mass balance.

5.1 Waste Input/Load and Stack flow

Nominally ten waste charges of 26 lb (12 kg) each were fed each day into alternating gasification chambers of the MAGS unit. The waste type and feed schedule are shown in Table 5-1. The average waste load and stack flow for all runs were 55 ± 14 lb/h (22 ± 6.3 kg/h) and 148 ± 11 ft³/min (4.6 ± 0.30 m³/min), respectively (Table 5-2). Automatic MAGS system shut-downs were common and were due to a variety of reasons, the foremost being a faulty water pump.

Table 5-1. Feed schedule for each waste type and run, time in hh:mm and mass in lb.

SW-1 07/10/2015		SW-2 07/11/2015		SW-3 07/12/2015		HP-1 07/13/2015		HP-2 07/13/2015		KMC 07/14/2015		FSR-1 07/15/2015		FSR-2 07/16/2015	
Time	Mass	Time	Mass	Time	Mass	Time	Mass	Time	Mass	Time	Mass	Time	Mass	Time	Mass
10:41	19.3	14:53	19.6	11:05	18.5	11:12	17.9	15:42	17.5	13:46	9.0	13:28	23.7	13:02	24.1
10:52	18.5	15:31	18.6	11:16	18.3	11:21	18.3	15:51	18.3	13:54	20.5	13:48	23.2	13:11	23.8
11:03	17.9	15:40	18.9	11:26	18.6	11:37	18.5	16:44	18.4	14:10	27.7	14:00	22.8	13:20	22.9
11:23	17.8	15:57	17.9	11:46	17.5	12:08	18.1	16:54	17.9	14:32	9.1	14:21	22.7	13:29	22.8
11:43	19.8	16:23	18.1	11:54	19.7	12:34	17.9	17:45	18.0	14:47	10.6	14:30	24.5	14:27	25.2
11:55	17.8	16:31	17.8	12:04	17.6	12:43	18.0			14:56	23.6	15:20	22.6	14:35	23.1
12:19	17.7	16:41	17.7	12:26	17.6	13:19	18.2			15:06	12.9	15:28	22.6	15:44	23.0
12:32	18.9	17:20	19.1	13:15	18.6	13:29	19.4			15:14	13.7	16:43	23.4	15:55	23.7
12:54	18.8	17:29	18.7	13:24	18.8	13:55	17.8			15:24	5.6	16:56	24.0	16:28	24.1
13:03	17.5	17:59	17.5	13:33	17.8	14:04	18.5			15:33	6.4	17:23	22.9	16:41	22.7
13:37	18.5	18:08	18.4	14:05	17.3	14:46	18.0			15:42	8.5	17:32	23.6	17:15	23.7
13:54	17.8	18:40	17.4	14:13	17.4	14:55	18.0			15:52	24.1	18:06	22.8		
14:22	17.8	18:49	17.3	14:23	19.1					16:01	22.2				
14:32	19.3	19:14	19.9	14:31	18.3					16:17	12.1				
14:58	17.1	19:23	19.6	14:41	17.6					16:28	7.1				
15:10	18.9	19:32	21.4	14:50	18.9					16:43	7.8				
15:41	6.4			11:05	18.5					16:57	10.7				
				11:16	18.3					17:11	3.0				
										17:25	14.2				
										17:34	12.3				

Table 5-2. Average waste load and stack flow for each waste type as well as all-run average.^a

	SW	HP	KMC	FSR	Avg. of all Waste Types
Waste load (lb/h)	62±10	39 (25%)	65	57 (0.65%)	55±14
Waste load (kg/h)	28±4.7	18 (25%)	30	26 (0.65%)	25±6.3
Stack flow (ft ³ /min)	147±6.4	158 (0.66%)	150	137 (8.8%)	148±11
Stack flow (m ³ /min)	4.2±4.4	4.5 (0.66%)	4.2	3.9 (8.8%)	4.2±0.30

^a Range denoted 1 STDV. Relative percent difference within parentheses.

5.2 Continuous Emissions Monitoring

Average FTIR concentrations and emissions factors for ten gases of interest are shown in Table 5-3 and Table 5-4, the latter calculated using the carbon mass balance approach. Values presented are the same-waste averages of the whole-run mean concentrations. High variability is noted particularly for CO, CH₄, and SO₂, likely a result of the cyclic, batch process. Appendix A shows the maximum, minimum, and average for each run. No substantial difference in the average CEM stack gas concentrations emerged between the different waste types. MAGS unit shutdowns were observed, beginning with run SW-3, which resulted in two very large CO peaks (Figure 5-2), significantly above the CEM factory span range of 1,000 ppm. Similar increases were observed for CH₄ (not shown) while CO₂ concentrations dropped. All CEM data during shutdowns were excluded from the CEM averages and subsequent emissions factor calculations due to the significant uncertainty of their values. Subsequently, shutdowns of the MAGS system occurred for runs HP-1, HP-2, and FSR-1. To avoid clogging sampling lines with excessive PM, emissions sampling was promptly ceased during shutdowns after SW-3 and resumed upon normal operation.

Table 5-3. CEM average concentrations for ten gases. For comparison purposes the regulatory limits according to EPA OSWI [2] for NO_x, SO₂, HCl, and CO are 103, 3.1, 15, 40 ppm dry, respectively.

Pollutant	Units	SW		HP		KMC	FSR		Avg. of all Waste Types	
		Average	CV/RPD (%)	Average	RPD (%)		Average	RPD (%)	Average	CV (%)
NO _x as (NO ₂)	dry PPM	196	5.1	143	2.4	254	257	1.4	207	25
NO	dry PPM	187	16	143	1.7	249	273	0.53	188	41
NO ₂	dry PPM	6.4	5.8	4.4	21	14	13	24	8.8	54
SO ₂	dry PPM	0.05	100	0.011	27	0.16	0.44	30	0.16	137
HCl	dry PPM	0.46	12	0.57	21	0.66	1.4	28	0.79	62
CO	dry PPM	68	80	101	43	190	39	46	86	70
CO ₂	dry Vol-%	9.9	0.08	9.4	2.1	8.3	9.8	0.60	9.5	6.0
CH ₄	dry PPM	0.57	80	0.75	74	1.0	0.42	95	0.65	83
O ₂	dry Vol-%	9.0	10 ^b	9.0	0.50	9.33	8.7	0.42	9.0	6.0
H ₂ O	Vol-%	9.5	5.3	9.4	5.1	9.62	11	2.6	10	10

^a RPD = relative percent difference, CV = coefficient of variance. ^b Coefficient of variance.

Table 5-4. CEM emissions factors for ten gases using the carbon mass balance approach.

Pollutant	Units	SW		HP		KMC	FSR		Avg. of all Waste Types	
		Average	RPD (%)	Average	RPD (%)	Average	Average	RPD (%)	Average	CV (%)
NO _x (as NO ₂)	g/kg waste	2.9	5.0	3.0	4.6	5.5	5.3	1.9	4.0	33
NO	g/kg waste	2.0	5.3	1.9	3.9	3.9	3.6	1.1	2.7	35
NO ₂	g/kg waste	0.095	5.7	0.10	23	0.30	0.27	25	0.17	63
SO ₂	g/kg waste	0.0003	N/A	0.0002	29	0.0025	0.0062	30	0.0026	122
HCl	g/kg waste	0.0054	12	0.0093	19	0.011	0.023	28	0.012	69
CO	g/kg waste	0.61	34	1.3	41	2.5	0.48	46	1.0	79
CO ₂	g/kg waste	1,396	0.024	1,842	0.04	1,714	1,912	0.019	1,716	13
CH ₄	g/kg waste	0.0029	89	0.0053	73	0.0078	0.0030	95	0.0037	85

^a RPD = Relative percent difference, CV = Coefficient of variance. N/A = Not applicable = only detected in one sample.

Typical real time FTIR results for CO₂ and CO are shown in Figure 5-1 and Figure 5-2 with the waste load times and emissions sampling times noted.

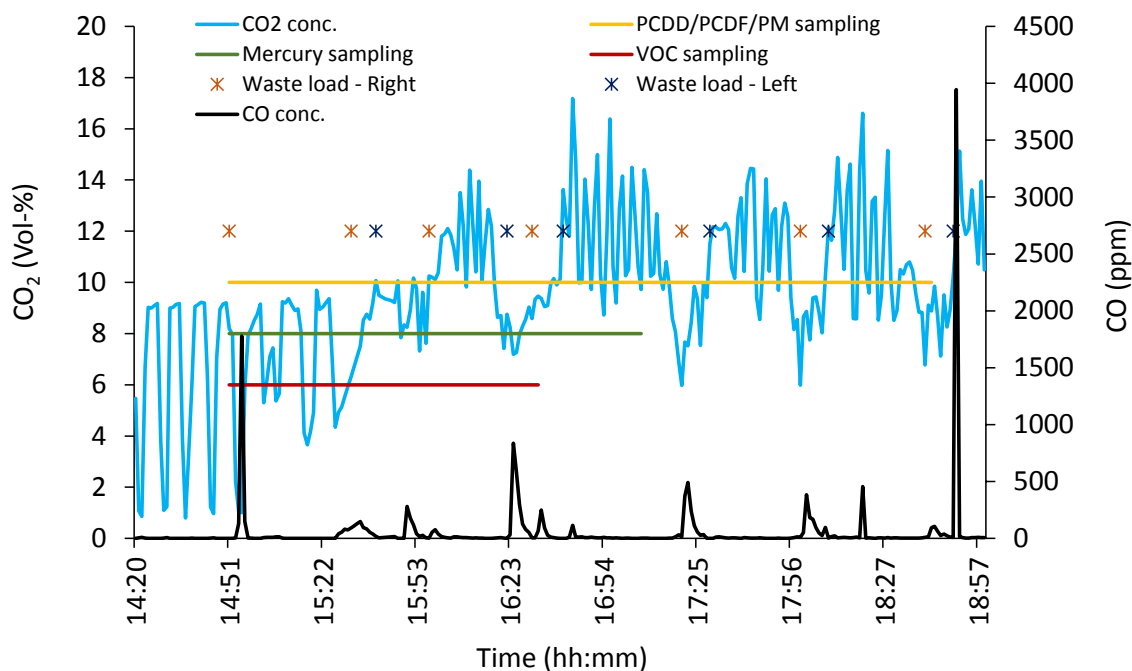


Figure 5-1. Real time CO₂ and CO concentration versus time as well as the timing of waste loads and sample collection for VOCs, PM, mercury, and PCDD/PCDF/PAH during run number SW-2.

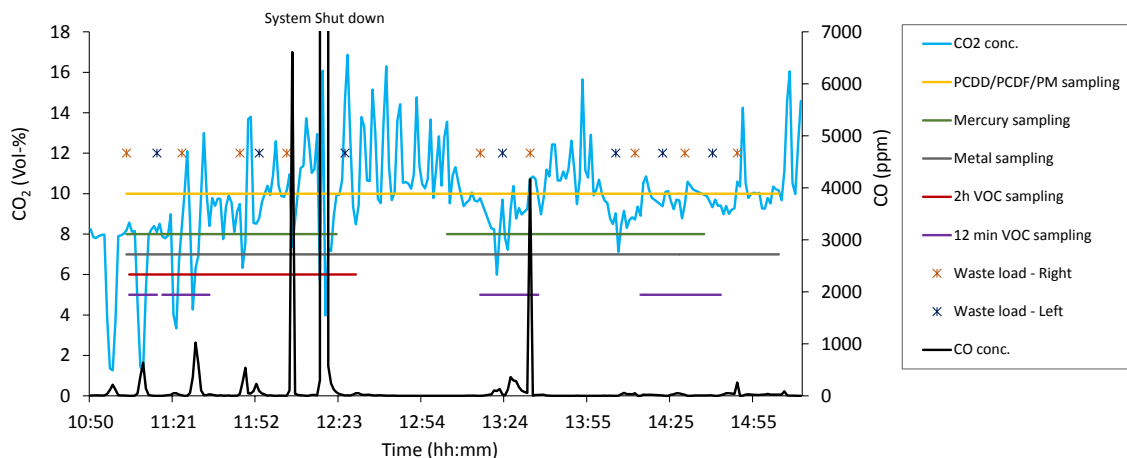


Figure 5-2. Real time CO_2 and CO concentration versus time as well as the timing of waste loads and sampling collection for VOCs (one 2-h sample and four 12-min samples), PM, Metal/PM, mercury, and PCDD/PCDF/PAH during run number SW-3.

During the course of the testing, seven unexpected shutdowns (some test runs had multiple shutdowns) occurred with the MAGS unit. The first automatic MAGS shutdown (SW-3) resulted in high spikes in the CEM readings (e.g., CO) that were beyond the factory calibration range of our CEMs. Sampling during subsequent shutdowns was suspended during the outage to prevent filter clogging from truncating the sampling effort. A 2-h SUMMA canister sample spanned this SW-3 shutdown and showed significantly higher concentrations of benzene and naphthalene compared to canisters from SW-1 and SW-2, both of which sampled without shutdowns. Batch samples such as PM, mercury, and PCDD/PCDF showed no, or minimal, apparent increase from SW-3 to SW-1 and SW-2, likely because the shutdown period was very short compared to the length of the sampling. The PAH SW-3 sample showed higher concentrations compared to samples from SW-1 and SW-2. PAHs, benzene, and naphthalene are common products of incomplete combustion, indicative of suboptimal conditions during the unexpected shutdown.

5.3 Particulate Matter Emissions

5.3.1 Integrated Sampling

PM concentrations in the stack and emissions factors from the U.S. EPA Method 5 filter and Modified Method 5 using a 37-mm Teflon filter are shown in Table 5-5. Results are presented as volumetric concentrations and in a ratio with waste mass fed, calculated from Table 5-1 and the carbon balance method (Equation 3-3). The full PM data set is shown in Appendix B. The PM concentrations were notably higher from gasification of the FSR waste type, $60 \pm 9.3 \text{ mg/m}^3$ at 7% O_2 , than the other waste composition types, $36 \pm 10 \text{ mg/m}^3$ at 7% O_2 (Figure 5-3). The two methods of PM concentration determination, “M5-PM” and “Teflon PM”, agree within an 18% difference of their respective averages, exclusive of FSR (see below). The low coefficient of variation (15%) and standard deviations for the three SW replicate tests (M5-PM) showed good reproducibility between the test runs.

A five-fold difference between the M5-PM and the Teflon PM for the FSR waste type was observed. The reason for this difference is not clear. The FSR Teflon PM values stand out as being significantly lower than their parallel M5-PM and in contrast with the agreement noted between the two methods for the other three waste types. There are differences in the methods; the most obvious is that the Teflon PM filter was heated to approximately 300 °F (149 °C) and the glass M5-PM filter was heated, according to Method 5, to 257 °F (125 °C), potentially leading to higher organics capture on the M5-PM filter. However, this doesn't explain the congruence with the other three waste types. Another distinction in the methods offering a potential explanation includes the difference in sampling time as the M5 sample was collected for 1 hour longer than the Teflon PM sample for each of the FSR tests. However, none of these explanations are definitive. In the absence of a clearer understanding of these different values, the standard EPA Method 5 results, M5-PM, should be considered the actual emissions values.

Table 5-5. PM stack concentrations and emissions factors from the M5-train and the Modified M5 using 37-mm Teflon filters.^a For comparison purposes, the regulatory limit according to EPA OSWI [2] for PM is 30 mg/m³ at 7% O₂.

Waste Type	Concentration (mg/m ³ at 7% O ₂)		Emissions Factor (g/kg waste) ^b		Emissions Factor (g/kg waste input) ^c	
	M5 - PM	Teflon PM	M5 - PM	Teflon PM	M5 - PM	Teflon PM
SW	39±5.8 ^d	38 (7.7%)	0.23 (15%)	0.30 (20%)	0.27±0.030 ^d	0.23 (7.5%)
HP	41 (9.5%)	34 (19%)	0.39 (10%)	0.24 (6.1%)	0.49 (25%)	0.41 (37%)
KMC	18	16	0.17	0.15	0.13	0.12
FSR	60 (16%)	13 (15%)	0.62 (4.7%)	0.12 (11%)	0.53 (29%)	0.087 (3.7%)
Avg. of all waste types	42±15 ^d	27±13 ^d	0.39±0.22 ^d	0.21±0.089 ^d	0.37±0.19 ^d	0.20±0.16 ^d

^a Relative percent difference within parentheses. ^b Carbon mass balance method. ^c Waste load. ^d 1 Standard deviation.

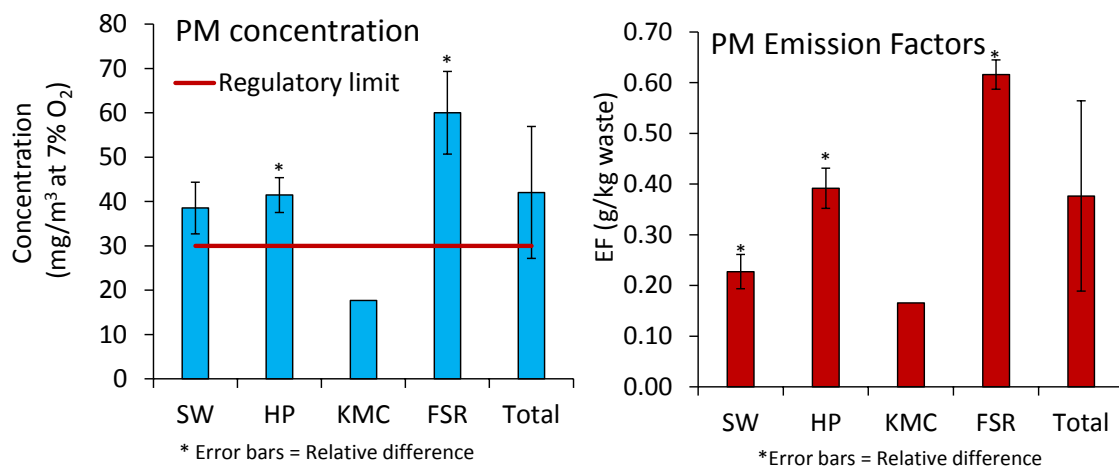


Figure 5-3. Stack concentrations and emissions factors (using the carbon mass balance) of Total PM (U.S. EPA Method 5). Error bars denote 1 standard deviation if nothing else is stated.

5.3.2 Real Time Sampling

The batch measurements of PM reported above were complemented by time-resolved analyses of PM_{2.5} and black carbon. Typical real time PM_{2.5} and BC traces as well as FTIR results for CO₂ and CO are shown in Figure 5-4. All runs were not analyzed for PM and BC due to high water content in the flue gas, leaving water spots on the optics, which interfere with the measurements. The real time data in Figure 5-4 revealed PM_{2.5} and BC peaks occurring during the shutdown of the MAGS unit during test SW-3. Data collection during subsequent shutdowns was stopped and so is not included in emissions factors. Other noticeable peaks are observed but do not correspond to the single shutdown encountered during the SW-3 sampling. As shown in Table 5-6, the PM size consisted mostly of PM₁ and less (PM with an aerodynamic diameter less than or equal to 1.0 µm).

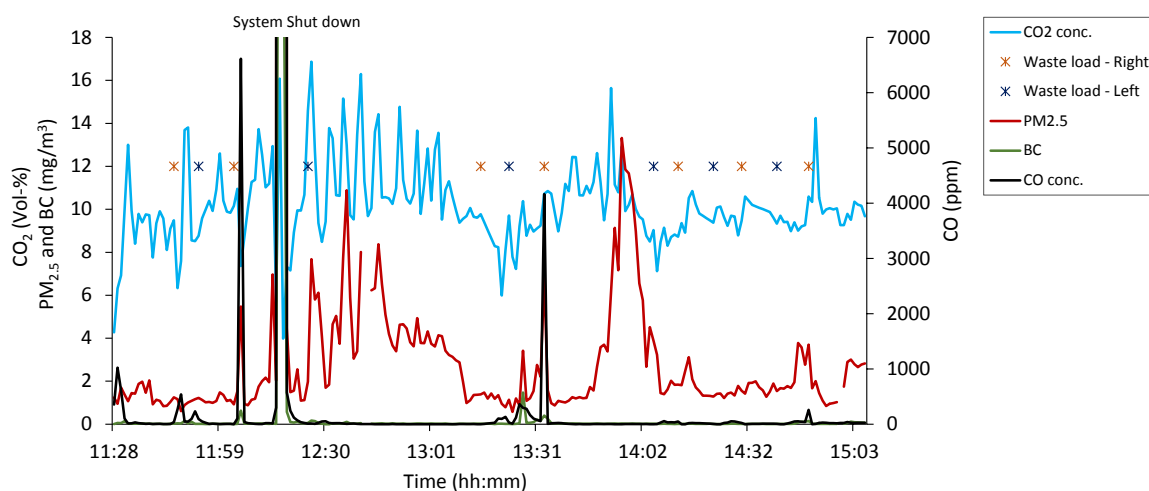


Figure 5-4. Real time CO₂, CO, PM_{2.5} and BC concentration during run SW-3.

Table 5-6. PM by size and black carbon concentrations and emissions factors collected in real time.^a For comparison purposes, the regulatory limit according to EPA OSWI [2] for PM is 30 mg/m³ at 7% O₂.

Waste	Unit	BC	PM ₁	PM _{2.5}	PM ₄	PM ₁₀	Total PM
SW	mg/m ³ at 7% O ₂	0.053	3.1	3.1	3.1	3.1	3.1
SW	mg/kg waste	0.00035	0.020	0.020	0.020	0.020	0.020
HP	mg/m ³ at 7% O ₂	0.47 (73%)	34 (44%)	34 (44%)	34 (44%)	34 (44%)	34 (44%)
HP	mg/kg waste	0.0043 (72%)	0.31 (42%)	0.31 (42%)	0.31 (42%)	0.31 (42%)	0.31 (42%)
KMC	mg/m ³ at 7% O ₂	0.25	11	11	11	11	11
KMC	mg/kg waste	0.0024	0.10	0.10	0.10	0.10	0.10
FSR	mg/m ³ at 7% O ₂	0.038	N/A	N/A	N/A	N/A	N/A
FSR	mg/kg waste	0.00036	N/A	N/A	N/A	N/A	N/A

^a Relative percent difference within parentheses. N/A = sample not valid.

5.4 Metals

5.4.1 Metals – XRF and ICP

Particle-bound metals on the 37-mm Teflon filter and gas phase mercury are reported in Table 5-7, Table 5-8, and Table 5-9 by volumetric concentrations, by the use of carbon mass balance (gasified/combusted) and by mass of waste input, respectively. The full XRF data set is reported in Appendix C.

Table 5-7. Metal stack concentrations.^a For comparison purposes, the regulatory limit according to EPA OSWI [2] for cadmium and lead is 18 and 226 $\mu\text{g}/\text{m}^3$ at 7% O_2 , respectively.

Metal	SW	HP	KMC	FSR	Avg. of all Waste Types
	$\mu\text{g}/\text{m}^3$ at 7% O_2				
Aluminum (Al) ^b	8.6	ND	2.9	ND	5.8 (49%)
Chloride (Cl) ^b	3,620	5,701	4,005	988	3,578 \pm 1,949
Iron (Fe) ^c	45 \pm 37	61 (41%)	4.7 ^b	40 (53%)	43 \pm 32
Copper (Cu) ^c	150 \pm 60	169 (29%)	66 ^b	174 (26%)	151 \pm 59
Cadmium (Cd) ^c	1.0 \pm 0.54	0.49 (16%)	0.26 ^b	ND	0.75 \pm 0.48
Lead (Pb) ^c	122 \pm 80	83 (13%)	31 ^b	61 (20%)	86 \pm 56

^a Relative percent difference (%) or standard deviation (\pm), ND = not detected, ^b XRF single sample. ^c ICP.

Table 5-8. Metal emission factors using carbon mass balance method.^a

Metal	SW	HP	KMC	FSR	Avg. of all Waste Types
	mg/kg waste				
Aluminum (Al) ^b	0.090	ND	0.028	ND	0.059 (53%)
Chloride (Cl) ^b	38	32	38	12	30 \pm 12
Iron (Fe) ^c	0.31 (61%)	0.41 (18%)	0.045 ^b	0.34 (32%)	0.31 \pm 0.18
Copper (Cu) ^c	1.0 (15%)	1.2 (4.7%)	0.63 ^b	1.6 (0.50%)	1.2 \pm 0.33
Cadmium (Cd) ^c	0.0089 (10%)	0.0038 (39%)	0.0024 ^b	ND	0.0058 \pm 0.0031
Lead (Pb) ^c	0.92 (36%)	0.64 (37%)	0.29 ^b	0.62 (43%)	0.66 \pm 0.35

^a Relative percent difference within parentheses, ND = not detected, ^b XRF single sample. ^c ICP.

Table 5-9. Metal emissions factors by waste input.^a

Metal	SW	HP	KMC	FSR	Avg. of all waste types
	mg/kg waste input				
Aluminum (Al) ^b	0.060	ND	0.021	ND	0.040 (48%)
Chloride (Cl) ^b	25	78	29	7.5	35 \pm 87
Iron (Fe) ^c	0.26 (68%)	0.76 (55%)	0.034 ^b	0.26 (45%)	0.37 \pm 0.39
Copper (Cu) ^c	0.80 (27%)	2.1 (46%)	0.48 ^b	1.2 (15%)	1.2 \pm 0.83
Cadmium (Cd) ^c	0.0069 (23%)	0.0055 (2.7%)	0.0019 ^b	ND	0.0055 \pm 0.0021
Lead (Pb) ^c	0.73 (47%)	0.93 (5.9%)	0.22 ^b	0.43 (30%)	0.63 \pm 0.35

^a Relative percent difference within parentheses, ND = not detected, ^b XRF single sample. ^c ICP.

5.4.2 Mercury

Mercury concentrations and emissions factors are shown in Table 5-10 and Figure 5-5. Results for each collected sample are reported in Appendix C. The mercury emissions concentration was lower for the waste with higher plastic content (HP), $0.31 \pm 0.037 \mu\text{g}/\text{m}^3$ at 7% O_2 , than the other waste types, 0.53 - $0.73 \mu\text{g}/\text{m}^3$ at 7% O_2 . However, little difference between the waste types was noticeable when dividing the cumulative mercury amount in the stack with the total amount of waste gasified (i.e., the emission factor) during the same time period.

Table 5-10. Mercury stack concentrations and emissions factors for each waste type.^a For comparison purposes, the regulatory limit according to EPA OSWI [2] for mercury is $74 \mu\text{g}/\text{m}^3$ at 7% O_2 .

Compound	Unit	SW	HP	KMC	FSR	Avg. of all Waste Types
Mercury	$\mu\text{g}/\text{m}^3$ at 7% O_2	0.73 ± 0.18	0.31 ± 0.037	0.53 (14%)	0.65 ± 0.10	0.60 ± 0.21
Mercury	$\mu\text{g}/\text{kg}$ waste ^b	6.5 ± 3.3	2.9 ± 0.50	4.9 (17%)	6.3 ± 1.8	5.2 ± 2.4
Mercury	$\mu\text{g}/\text{kg}$ waste input	4.1 ± 0.81	3.4 ± 0.77	4.0 (19%)	3.8 ± 0.55	3.9 ± 0.77

^a Relative per cent difference within parentheses. Range of date denoted 1 standard deviation. ^b Carbon mass balance method.

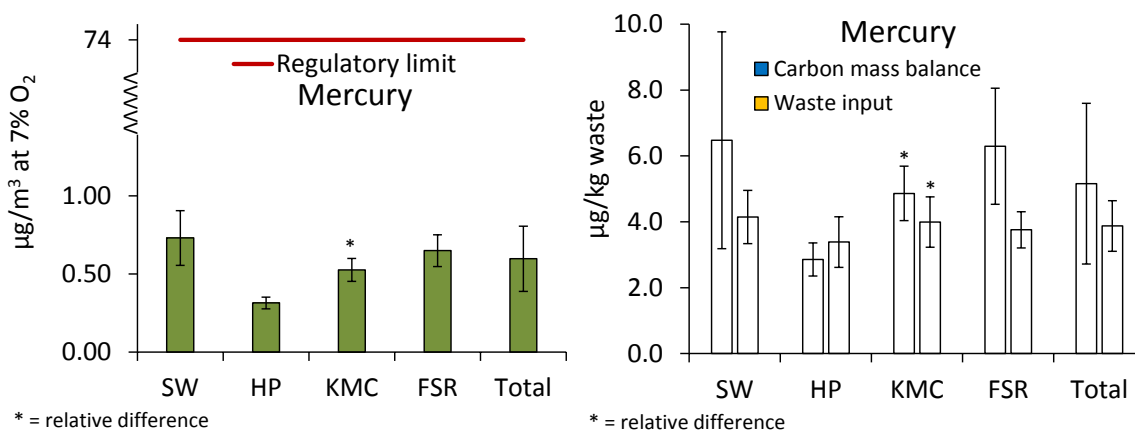


Figure 5-5. Mercury stack concentrations and emissions factors for each waste type as well as a total average of all waste types. Error bars denote 1 STDV if nothing else is stated.

5.5 Volatile Organic Compounds

Select VOC stack concentrations and emissions factors by SUMMA canister collection/analysis are reported in Figure 5-6, Table 5-11, and Table 5-12 (the full data set is reported in Appendix D). Benzene, toluene, and propene were the most abundant VOCs for all waste types. The higher benzene concentration for the SW tests is most probably due to the rapid system shut-down/start-up on SW (only) since benzene is a byproduct of incomplete combustion. A higher benzene concentration was also found at the very start of each waste load and decreased with run time, shown in Figure 5-7. The higher levels of vinyl chloride, vinyl acetate, and

chloromethane from gasification of FSR waste may be due to the higher salt and compositional content in the FSR food and/or the addition of FSR packaging material.

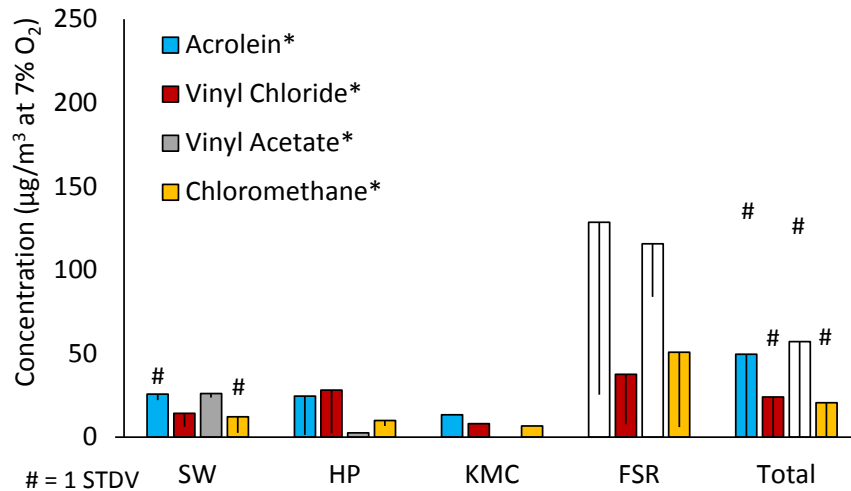


Figure 5-6. Selected VOCs from each of the waste types. Error bars denote relative difference if nothing else is stated. * = VOCs on EPA's list of Hazardous Pollutants (HAP List) [1].

Table 5-11. Selected VOC stack concentrations.^a

Compound	SW		HP		KMC	FSR		Avg. of all Waste Types	
	µg/m³ at 7% O₂	CV/RPD %	µg/m³ at 7% O₂	RPD %		µg/m³ at 7% O₂	RPD %	µg/m³ at 7% O₂	CV %
Propene	73	22	73	96	18	243	82	109	131
Chloromethane ^b	12	79	10	32	6.8	51	88	21	150
Vinyl Chloride ^b	14	57 ^c	28	92	8.1	38	79	24	108
Acrolein ^b	26	14	25	94	13	129	80	50	151
Acrylonitrile ^b	7.1	47 ^c	8.9	87	7.2	36	84	16	143
Methylene Chloride ^b	4.1	59 ^c	2.2 ^d	5.3	5.6	5.7	21	4.2	53
Vinyl Acetate ^b	26	9.0 ^c	2.6 ^d	N/A	ND	116	27	57	103
2-Butanone (MEK)	15	3.9 ^c	7.3	47	13	195	7.9	64	141
Benzene ^b	4,377 ^e	170	666	42	1,458	1,119	88	2,270	193
Toluene ^b	84	156	16	46	644	137	62	150	147
Chlorobenzene ^b	6.6	76	10	87	6.0	16	55	10	85
Ethylbenzene	1.1 ^d	20	7.3	N/A	219	45	60	53	161
<i>m,p</i> -Xylenes ^b	1.4 ^d	62	3.9 ^d	N/A	52	13	34	14	140
<i>o</i> -Xylene ^b	0.63 ^d	25 ^c	ND	N/A	29	6.4	27	8.6	138
Benzyl Chloride ^b	4.2	81 ^c	0.58 ^d	42	7.4	14	57	6.4	118
Naphthalene	165	160	43	90	304	244	77	172	115

^a ND = not detected, N/A = not applicable (only one sample detected or all samples non detect). RPD = relative percent difference, CV = coefficient of variance. ^b On EPA's list of Hazardous air pollutants (HAP List) [1]. ^c RPD. ^d Less than three times the detection limit. ^e Sampled during the system shut-down during test SW #3 (12,951 ug/m³), the average for test SW #1 and SW #2 was 90 ug/m³ with a RPD of 5.1%.

Table 5-12. Selected VOC emissions factors derived from the carbon mass balance method (units in mg/kg waste).

Compound	SW		HP		KMC	FSR		Avg. of all Waste Types	
	mg/kg	CV/ RPD %	mg/kg	RPD %	mg/kg	mg/kg	RPD %	mg/kg	CV %
Propene	9.5E-01	95	7.8E-01	96	2.0E-01	2.9E+00	89	1.3E+00	140
Chloromethane ^b	2.0E-01	132	1.1E-01	32	7.5E-02	6.2E-01	93	2.6E-01	153
Vinyl Chloride ^b	9.5E-02	54 ^c	3.0E-01	91	9.0E-02	4.5E-01	87	2.5E-01	126
Acrolein ^b	2.9E-01	62	2.6E-01	94	1.5E-01	1.5E+00	87	5.8E-01	164
Acrylonitrile ^b	4.7E-02	44 ^c	9.5E-02	87	7.9E-02	4.3E-01	90	1.8E-01	165
Methylene Chloride ^b	2.7E-02	57 ^c	2.3E-02 ^d	5.1	6.2E-02	6.1E-02	43	4.1E-02	64
Vinyl Acetate ^b	1.8E-01	4.9 ^c	2.8E-02 ^d	N/A	ND	1.2E+00	48	5.7E-01	130
2-Butanone (MEK)	1.0E-01	7.9 ^c	7.7E-02	47	1.5E-01	2.0E+00	31	6.4E-01	154
Benzene ^b	9.5E+01	172	7.1E+00	42	1.6E+01	1.4E+01	92	4.3E+01	228
Toluene ^b	1.8E+00	168	1.7E-01	46	7.1E+00	1.6E+00	74	2.0E+00	139
Chlorobenzene ^b	4.4E-02	51 ^c	1.0E-01	87	6.6E-02	1.9E-01	69	1.0E-01	105
Ethylbenzene	7.1E-03 ^d	10 ^c	7.7E-02	N/A	2.4E+00	5.2E-01	73	5.9E-01	162
<i>m,p</i> -Xylenes ^b	9.0E-03 ^d	41 ^c	4.2E-02 ^d	N/A	5.8E-01	1.4E-01	53	1.5E-01	146
<i>o</i> -Xylene ^b	4.3E-03 ^d	21 ^c	ND	N/A	3.2E-01	6.8E-02	48	9.4E-02	143
Benzyl Chloride ^b	2.8E-02	80 ^c	6.2E-03 ^d	41	8.2E-02	1.6E-01	71	6.7E-02	143
Naphthalene	3.5E+00	169	4.6E-01	90	3.4E+00	2.9E+00	85	2.6E+00	143

^a ND = not detected, N/A = not applicable (only one sample detected or all samples non detect). RPD = relative percent difference, CV = coefficient of variance. ^b On EPA's list of Hazardous air pollutants (HAP List) [1]. ^c RPD. ^d Less than three times the detection limit.

One run of the standard waste (SW-3), selected at random, was sampled for VOCs over a 3.5-hour period with four SUMMA canister samples (Table 5-13). The SUMMA canisters sampled for periods ranging from 10 to 30 min. The resulting concentrations of the three major species are plotted in Figure 5-7 against the waste charge timing of the MAGS unit.

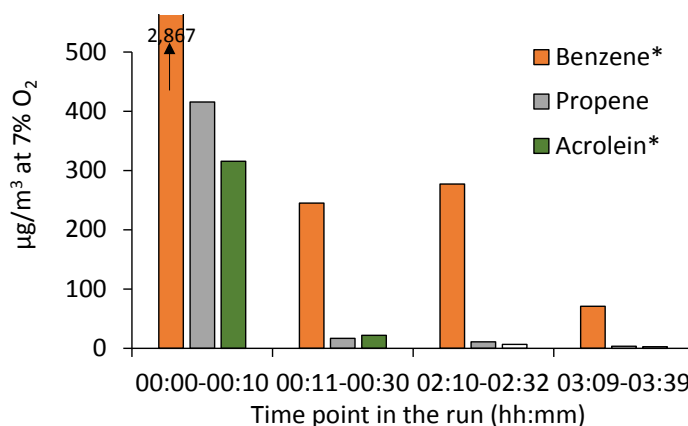


Figure 5-7. VOC concentration vs. time point in the run for three major VOCs. * = VOCs on EPA's list of Hazardous Air Pollutants (HAP List) [1]. Run # SW-3.

Table 5-13. VOC concentrations over run time.

Collection Time Compound	SW-3 µg/m ³ at 7% O ₂			
	00:00-00:10	00:11-00:30	02:10-02:32	03:09-03:39
Propene	416	17	11	3.5
Chloromethane ^b	33	7.1	5.2	0.64 ^c
Vinyl Chloride ^b	34	48	12	0.79 ^c
Acrolein ^b	315	22	6.6	2.4
Acrylonitrile ^b	11 ^c	13	18	0.65 ^c
Methylene Chloride ^b	ND	5.9	2.8	0.73 ^c
Vinyl Acetate ^b	37 ^c	4.6	ND	2.9 ^c
2-Butanone (MEK)	23	7.9	29	5.3
Benzene ^b	2,867	245	277	71
Toluene ^b	87	2.6	8.6	2.3
Chlorobenzene ^b	17	8.9	2.8	0.82
Ethylbenzene	20 ^c	0.70 ^c	0.63 ^c	0.31 ^c
<i>m,p</i> -Xylenes ^b	ND	1.3	ND	ND
<i>o</i> -Xylene ^b	ND	0.76 ^c	0.48 ^c	0.32 ^c
Benzyl Chloride ^b	ND	2.3	0.89 ^c	0.58 ^c
Naphthalene	96	36	491	107

^a ND = not detected. ^b On EPA's list of Hazardous Air Pollutants (HAP List) [1]. ^c Less than three times the detection limit.

5.6 PCDD/PCDF/PAH

5.6.1 PCDD/PCDF

Data for PCDD/PCDF emissions are shown in Table 5-14 and Figure 5-8. Results of each sample collected are shown in Appendix E. The PCDD/PCDF stack concentration when gasifying SW, HP, and KMC waste were all similar, 0.26-0.27 ng TEQ/m³ at 7% O₂, while gasifying FSR waste generated a notably higher stack concentration of 0.68 ng TEQ/m³ at 7% O₂. The rapid system shut-down during test SW-3 (the only sample for which sampling was not suspended during shutdowns) did not have a large effect on the PCDD/PCDF results as the stack concentration for the three SW runs had a relative standard deviation of less than 18% (9.3/53).

Table 5-14. PCDD/PCDF concentrations and emissions factors from each waste type.^a For comparison purposes, the regulatory limit according to EPA OSWI [2] for ΣPCDD/PCDF is 33 ng/m³ at 7% O₂.

	Unit	SW	HP	KMC	FSR	Avg. of all Waste Types
ΣPCDD/PCDF TEQ	ng TEQ/m ³ at 7% O ₂	0.27±0.059 ^b	0.27 (6.8%)	0.26	0.68 (3.4%)	0.37±0.19 ^b
ΣPCDD/PCDF	ng/m ³ at 7% O ₂	53±9.3 ^b	54 (12%)	61	108 (9.0%)	68±26 ^b
ΣPCDD/PCDF TEQ	ng TEQ/kg waste ^c	1.7 (20%)	2.5 (6.1%)	2.5	7.1 (7.5%)	3.6±2.4 ^b
ΣPCDD/PCDF	ng/kg waste ^c	300 (13%)	507 (11%)	573	1,112 (2.0%)	635±343 ^b
ΣPCDD/PCDF TEQ	ng TEQ/kg waste input	1.9±0.40	3.1 (9.6%)	1.9	5.9 (18%)	3.4±1.9 ^b
ΣPCDD/PCDF	ng/kg waste input	365±53 ^b	613 (4.6%)	443	944 (23%)	613±280 ^b

^a relative per cent difference within parentheses. ^b 1 standard deviation. ^c Carbon mass balance method.

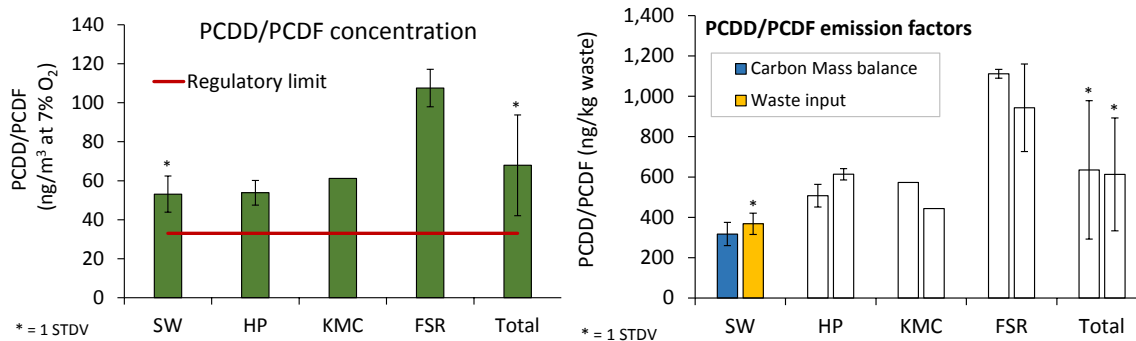


Figure 5-8. PCDD/PCDF concentrations and emissions factors from each waste type. Error bars denoted relative difference if nothing else is stated.

5.6.2 PAHs

The concentration and emissions factor of the sum of the 16 EPA PAHs are shown in Tables 5-15 to Table 5-18. Figure 5-9 shows the next most abundant PAHs after naphthalene. Results of each sample collected are shown in Appendix E. The high PAH levels ($2,389 \pm 2,383 \mu\text{g}/\text{m}^3$ at 7% O₂) for gasification of SW were most probably due to the system shut-down/start-up during run SW-3. The average PAH concentration for run SW-1 and SW-2 was $1,053 \mu\text{g}/\text{m}^3$ at 7% O₂ with an RPD of 54%, which is five times lower than from SW-3 ($5,061 \mu\text{g}/\text{m}^3$ at 7% O₂) and similar to the emissions levels of the three other waste types.

Table 5-15. Sum of the 16 EPA PAH concentrations and emissions factors from each waste type.^a

	Unit	SW	HP	KMC	FSR	Avg. of all Waste Types
ΣPAH	μg/m ³ at 7% O ₂	2,389±2,383	685 (1.3%)	994	1,101 (58%)	1,467±1,533
ΣPAH TEQ	μg B[a]P TEQ/m ³ at 7% O ₂	33±42	6.8 (3.4%)	6.1	6.9 (26%)	17±27
ΣPAH	mg/kg waste ^c	18 (83%)	6.5 (0.68%)	9.3	13 (65%)	11±9.8
ΣPAH TEQ	μg B[a]P TEQ/kg waste ^c	250 (84%)	69 (4.6%)	57	92 (36%)	126±150
ΣPAH	mg/kg waste input	16±17	7.9 (15%)	7.2	8.7 (48%)	11±11
ΣPAH TEQ	μg B[a]P TEQ/kg waste input	231±293	86 (20%)	44	65 (12%)	137±191

^a Range denoted is 1 STDV. Relative per cent difference (RPD) within parentheses. If no range or RPD is stated, only one sample with detectable levels. ^c Carbon mass balance method.

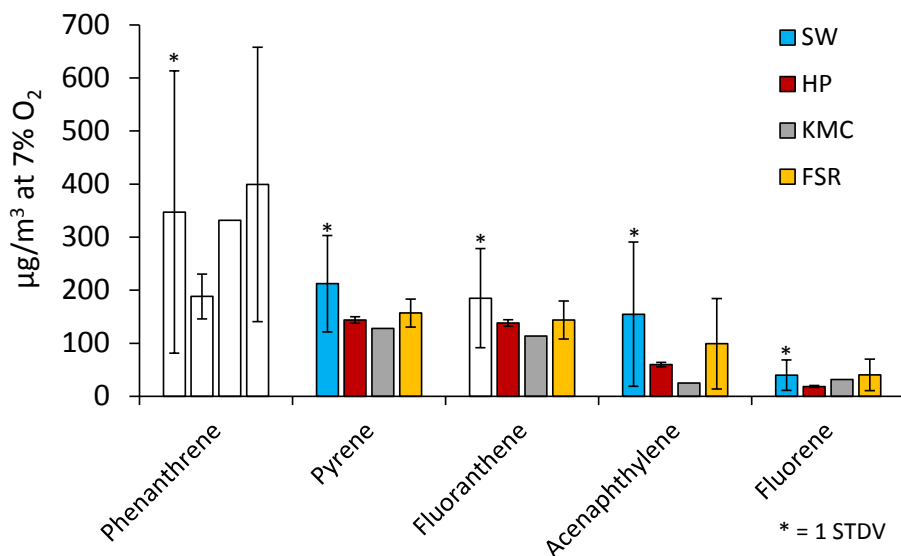


Figure 5-9. The five most abundant PAHs (except for naphthalene) from the four waste types. Error bars denote relative difference if nothing else is stated.

Table 5-16. PAH concentrations for each waste type in $\mu\text{g}/\text{m}^3$ at 7% O_2 .^a

Compound	SW	HP	KMC	FSR	Avg. of all Waste types
	$\mu\text{g}/\text{m}^3$ at 7% O_2				
Naphthalene	1,310±1,586	117 (12%)	332	213 (84%)	615±1,031
Acenaphthylene	155±136	60 (6.8%)	25	99 (86%)	101±99
Acenaphthene	3.0±1.3	1.2 (23%)	4.8	4.3 (45%)	3.1±1.8
Fluorene	40±29	19 (10%)	32	41 (73%)	34±24
Phenanthrene	347±266	188 (22%)	332	399 (65%)	319±217
Anthracene	20±14	10 (1.1%)	20	33 (67%)	21±16
Fluoranthene	185±93	138 (4.4%)	113	144 (25%)	154±60
Pyrene	212±91	144 (4.2%)	128	157 (17%)	171±62
Benzo(a)anthracene	8.6±11	2.9 (32%)	2.5	4.0 (19%)	5.2±6.6
Chrysene	14±20	4.4 (11%)	4.3	6.7 (19%)	8.6±12
Benzo(b)fluoranthene	24 (88%)	ND	ND	ND	24 (88%)
Benzo(k)fluoranthene	19 (85%)	ND	ND	ND	19 (85%)
Benzo(a)pyrene	25 (86%)	ND	ND	ND	25 (86%)
Indeno(1,2,3-cd)pyrene	29 (96%)	0.31	ND	0.22	15±28
Dibenz(a,h)anthracene	2.3 (93%)	ND	ND	ND	2.3 (93%)
Benzo(ghi)perylene	41 (96%)	0.46	0.30	0.35	17±36
SUM 16-EPA PAHs	2,389±2,383	685 (1.3%)	994	1,101 (58%)	1,467±1,533

^a ND = not detected. Range denotes 1 STDV. Relative per cent difference (RPD) within parentheses. If no range or RPD is stated, only one sample showed detectable levels.

Table 5-17. PAH emissions factors using the carbon mass balance method for each waste type in mg/kg waste.^a

Compound	SW	HP	KMC	FSR	Avg. of all Waste Types
	mg/kg waste				
Naphthalene	9.9 (99%)	1.1 (12%)	3.1	2.4 (87%)	4.2±6.7
Acenaphthylene	0.95 (88%)	0.56 (7.4%)	0.23	1.1 (88%)	0.79±0.83
Acenaphthene	0.017 (45%)	0.011 (23%)	0.045	0.047 (53%)	0.028±0.023
Fluorene	0.23 (76%)	0.18 (10%)	0.30	0.46 (78%)	0.29±0.26
Phenanthrene	2.4 (66%)	1.8 (22%)	3.1	4.5 (71%)	2.9±2.4
Anthracene	0.13 (62%)	0.10 (0.45%)	0.19	0.37 (72%)	0.20±0.20
Fluoranthene	1.3 (41%)	1.3 (5.1%)	1.1	1.5 (35%)	1.3±0.47
Pyrene	1.5 (34%)	1.4 (4.9%)	1.2	1.7 (27%)	1.5±0.43
Benzo(a)anthracene	0.072 (83%)	0.027 (32%)	0.024	0.042 (29%)	0.044±0.041
Chrysene	0.12 (87%)	0.042 (12%)	0.040	0.071 (29%)	0.073±0.073
Benzo(b)fluoranthene	0.28	ND	ND	ND	0.28
Benzo(k)fluoranthene	0.22	ND	ND	ND	0.22
Benzo(a)pyrene	0.29	ND	ND	ND	0.29
Indeno(1,2,3-cd)pyrene	0.35	0.0029	ND	0.0025	0.12±0.20
Dibenz(a,h)anthracene	0.027	ND	ND	ND	0.027
Benzo(ghi)perylene	0.50	0.0043	0.0028	0.0041	0.13±0.25
SUM 16-EPA PAHs	16 (81%)	6.5 (0.68%)	9.3	12 (65%)	12±10

^a ND = not detected. Range denoted is 1 STDV. Relative per cent difference (RPD) within parentheses. If no range or RPD is stated, only one sample showed detectable levels.

Table 5-18. PAH emissions factors for each waste type in mg/kg waste input.^a

Compound	SW	HP	KMC	FSR	Avg. of all Waste types
	mg/kg waste input				
Naphthalene	9.0±11	1.4 (28%)	2.4	1.6 (79%)	4.3±7.6
Acenaphthylene	1.1±0.94	0.70 (23%)	0.18	0.75 (82%)	0.75±0.72
Acenaphthene	0.021±0.0085	0.014 (38%)	0.035	0.035 (32%)	0.024±0.013
Fluorene	0.27±0.20	0.22 (26%)	0.23	0.31 (66%)	0.26±0.17
Phenanthrene	2.4±1.8	2.1 (6.3%)	2.4	3.1 (56%)	2.6±1.5
Anthracene	0.14±0.093	0.12 (15%)	0.15	0.26 (58%)	0.17±0.12
Fluoranthene	1.3±0.64	1.6 (21%)	0.82	1.2 (11%)	1.3±0.48
Pyrene	1.5±0.63	1.7 (20%)	0.93	1.3 (2.5%)	1.5±0.46
Benzo(a)anthracene	0.060±0.076	0.035 (46%)	0.018	0.033 (4.6%)	0.045±0.047
Chrysene	0.10±0.14	0.052 (27%)	0.031	0.056 (4.8%)	0.075±0.082
Benzo(b)fluoranthene	0.16 (89%)	ND	ND	ND	0.31 (89%)
Benzo(k)fluoranthene	0.13 (86%)	ND	ND	ND	0.25 (86%)
Benzo(a)pyrene	0.17 (87%)	ND	ND	ND	0.33 (87%)
Indeno(1,2,3-cd)pyrene	0.20 (96%)	0.0030	ND	0.0016	0.13±0.23

Dibenz(a,h)anthracene	0.016 (94%)	ND	ND	ND	0.030 (94%)
Benzo(ghi)perylene	0.29 (96%)	0.0045	0.0022	0.0026	0.14±0.28
SUM 16-EPA PAH	16±17	7.9 (15%)	7.2	8.7 (48%)	11±11

^a ND = not detected. Range denoted is 1 STDV. Relative per cent difference (RPD) within parentheses. If no range or RPD is stated, only one sample showed detectable levels.

5.7 Ash

Ash samples from each test were analyzed for mass percentage yield and metals concentration by XRF (Table 5-19).

Table 5-19. Ash percentage of total feed and metals concentration from each waste type.^a

	Unit	SW	HP	KMC	FSR	Avg. of all Waste Types
Ash: Total	%	12±4.0	15	11	9.0	12±3.3
Fine fraction	%	3.8±1.1	4.9	3.1	N/A	4.0±1.2
Coarse fraction	%	8.0±3.6	9.9	7.9	N/A	8.4±2.7
Chloride	g/kg ash	73±23	75	72	96	77±17
Aluminum	g/kg ash	36±5.2	33	38	64	41±12
Iron	g/kg ash	18±5.3	16	6.0	24	17±6.8
Magnesium	g/kg ash	8.9±1.9	11	8.1	7.0	8.9±1.9
Zinc	g/kg ash	11±1.2	10	5.2	17	11±3.7
Chromium	g/kg ash	1.7±0.91	2.4	0.63	0.45	1.4±0.93
Copper	g/kg ash	0.87±0.35	1.8	0.88	0.99	1.0±0.44
Lead	g/kg ash	0.20±0.068	0.23	0.11	0.18	0.19±0.061

^a Ash percentage = 100 × ash weight/total waste input weight. Range denoted: 1 STDV.

5.8 Scrubber Water Analyses

Six 1 L scrubber water samples, one after each day of operation (except FSR-1, 7/15/2015), were measured for pH and, as expected from a scrubber that is pH-controlled, the pH for all six samples was between 6 and 8. Overall, the chromatograms yielded hundreds of peaks, so dense that they overlapped into an indiscernible hump. The hump was much larger in the SW #2 and FSR #2 samples and minimal in the SW #3 and HP samples. When the total response in the chromatogram was compared to the area of the 5 µg spiked compounds, the results indicated a concentration between 0.8 and 16 mg/L of scrubber water (deionized water blanks were 0.2 and 0.6 mg/L). The largest peaks individually were in the 10 to 1000 µg/L range. This type of quantitation is very approximate because the mass response per compound on the GC/MS can vary by orders of magnitude.

The thirty largest peaks were tentatively identified as oxygenated hydrocarbons by an automatic library comparison of the spectra at the peak apex, using the NIST 2008 mass spectral library (200,000 compounds). The sample from KMC waste had many phenols in the thirty largest

peaks. In several samples, there were peaks that were identified as PAHs as well. All of the samples may have had these compounds but the level of other compounds may have pushed them out of the top thirty. Peaks tentatively identified as naphthalene or phenol were the largest individual peaks in four of the six samples.

5.9 Moisture

The stack moisture content measured using U.S. EPA Method 4 and the CEM H₂O concentration is shown in Table 5-20. Gasification of the FSR waste had a higher moisture level, 12.7 %, compared to the other waste types, 10.6%, which can be due to the difference in food type.

Table 5-20. Moisture content from each run as well as total of all runs.

	SW #1	SW #2	SW #3	HP #1	HP #2	KMC	FSR #1	FSR #2	Avg. of all Waste Types
Moisture ^a (Vol-%)	10.1	10.4	11.4	11.6	9.5	10.7	12.4	12.9	11.1±1.2
H ₂ O ^b (%)	N/A	9.8±1.8	9.9±1.5	8.9±1.5	9.9±1.1	9.6±0.70	11.1±1.4	11.7±1.3	10.0±1.1

^a Moisture from Method 5 train. ^b Water content analyzed by the FTIR CEM.

6 Discussion

The cyclical nature of this batch fed unit leads to considerable variation in emissions concentrations during normal operation, although multiple large swings in gas concentrations are observed even when no new waste is being introduced (see for example Figure 5-2, 12:30-13:00) due, at least in part, to the heterogeneous nature of the waste mixture. As calculated here, determination of average emissions factors includes the full scenario of the waste charging cycle to properly characterize the operation of the unit and its resultant emissions. Five (Pb, Cd, Hg, SO₂, and HCl) of the nine EPA-regulated compounds [2] were under their respective regulatory emissions limits (Table 6-1), while PCDD/PCDF, PM, NO_x, and CO emissions were all above the set emissions limits.

Table 6-1. MAGS stack emissions burning military waste compared to regulatory limits.^a

Compound	Unit	MAGS	Regulatory Limits EPA OSWI [2]
Σ PCDD/PCDF	ng/m ³ at 7% O ₂	68±26	33
PM	mg/m ³ at 7% O ₂	42±15	30
Mercury	µg/m ³ at 7% O ₂	0.60±0.21	74
Cadmium	µg/m ³ at 7% O ₂	0.75±0.48	18
Lead	µg/m ³ at 7% O ₂	86±56	226
NO _x	ppm dry	207±51	103
SO ₂	ppm dry	0.17±0.21	3.1
HCl	ppm dry	0.79±0.49	15
CO	ppm dry	86±66	40

^a Range denoted is 1 STDV. OSWI = Other Solid Waste Incinerators. ^b CO average includes test SW# 3 with large CO peak due to system shut-down. ^c CO average excluding test SW #3.

Comparison of our emissions data with those provided by Terragon Environmental Technologies Inc., the maker of the MAGS unit, is done in Table 6-2. Terragon sampled a high plastic municipal waste stream (“Terragon HP”) comprised of 62% plastic, 37% cellulosic material, and 1% water (metals and glass excluded). These data can perhaps be best compared against the HP waste tested here (“PACOM HP”). With the exception of Hg, every pollutant compound had higher emissions with the PACOM HP than with the Terragon HP test as well as the four-waste PACOM Total. This may be attributable in part to differences in waste composition and moisture content. Another likely explanation may be due to differences in sampling methods. The PACOM emissions sampling included all startups and partial shutdowns thereby capturing nearly the full range of realistic-operation emissions, while it is not clear this was done for the Terragon data.

Table 6-2. Comparison of MAGS Emissions Data.

Compound	Unit	Terragon HP ^a	This Study HP	This Study Avg. of all Waste Types
CO ₂	%	7.82	9.4	9.5
CO	ppm	30	101	86
PM	mg/m ³	0.80	41	42
NO _x	ppm	60	143	207
SO ₂	ppm	<1	0.011	0.17
HCl	ppm	0.56	0.57	0.79
PCDD/PCDF	ng/m ³	1.0	54	68
PCDD/PCDF	ng TEQ/m ³	0.001	0.27	0.37
PAHs	µg/m ³	<264	685	1,467
Hg	µg/m ³	0.814	0.31	0.6
Cd	µg/m ³	0.16	0.49	0.75
Pb	µg/m ³	3.7	83	86

^a Emissions Summary Report, Micro Auto Gasification System (MAGS™) V7, Terragon Environmental Technologies, Inc., Montreal, Canada, March 2015.

While regulatory limits are based on stack gas concentrations, more useful units for extrapolating to other waste technology systems and to evaluating overall burden to the environment are expressed through emissions factors. In this work, emissions factors have been calculated based on waste input amounts as well as on mass of carbon emissions. The waste feed rates were carefully determined for this work, allowing emissions factors to be calculated on a full day’s worth of waste inputs. To corroborate these emissions factor determinations, the carbon balance method was employed. The pollutant was co-measured with the major carbon species in the form of CO, CO₂, and CH₄. This carbon was then attributed to the carbon fraction in the waste, a value determined by an exhaustive waste composition

analysis linked with published carbon concentrations of materials. In comparing these two methods of analysis (for example, Table 5-15), the emissions factors based on waste input and the carbon balance were very similar. These emissions factors, pollutant mass per waste input amount, allow for extrapolation to other waste scenarios and comparisons with the performance of other waste technologies. Table 6-3 presents the MAGS emissions factors in comparison with other methods of waste disposal in the theatre, including an air curtain incinerator and a burn pile. The organic emissions and PM are higher from the incinerator and burn pile for a mass of waste burned basis but the metals, except for iron, are comparable. Of course, the waste compositions are very different between MAGS and the referenced study and there is a significant difference in the waste processing rate.

Table 6-3. MAGS emissions factors compared to emissions from open burning of simulated waste from forward operating bases, derived using the carbon mass balance method.^a

Compound	Unit	This Study MAGS	Burn box [29]	Burn pile [29]
Σ PCDD/PCDF TEQ	ng TEQ/kg waste	3.6±2.4	35±24	1,765±1,474
Σ PAH ^b	mg/kg waste	12±10	43±50	129±50
PM	g/kg waste	0.39±0.22	12±12 ^c	39±24 ^c
Iron	mg/kg waste	0.31±0.18	0.50±0.24	11±23
Copper	mg/kg waste	1.2±0.33	0.18±0.11	0.89±0.92
Cadmium	mg/kg waste	0.0058±0.0031	0.063±0.082	0.073±0.033
Lead	mg/kg waste	0.66±0.35	0.55±0.42	0.37±0.22
Benzene	mg/kg waste	43±98 ^d	243±299 ^d /1,371±185 ^e	260±288 ^d /2,421±1,265 ^e
Toluene	mg/kg waste	2.0±2.8 ^d	88±130 ^d /652±111 ^e	109±170 ^d /1,202±727 ^e
Acrolein	mg/kg waste	0.58±0.95 ^d	133±139 ^d /463±33 ^e	98±108 ^d /757±62 ^e
Vinyl chloride	mg/kg waste	0.25±0.32 ^d	3.7±2.5 ^d /13 ^e	6.0±5.5 ^d /26±3.3 ^e
Vinyl acetate	mg/kg waste	0.57±0.74 ^d	79±97 ^d /324±46 ^e	43±53 ^d /688±195 ^e

^a Range of data denoted 1 STDV. Relative percent difference within parentheses. ^b 16 EPA PAHs (see Table 5-16). ^c PM_{2.5}. ^d Modified combustion efficiency (MCE) > 0.95, MCE = CO₂/(CO₂+CO+CH₄). ^e MCE < 0.90.

7 Conclusions

The MAGS gasifier/combustor unit was emissions tested using four waste compositions simulating in-theatre standard waste as well as three challenge recipes evaluating compositional variations. Seven days of testing (~ 10 h/day) processed a daily average of 25 kg/h (55 lb/h) of waste during which emissions were sampled. The four-waste average emissions concentrations for metals (Cd, Pb, Hg), SO₂, and HCl were below OSWI regulatory limits while CO, NO_x, PM, and PCDD/PCDF were above limits. Some distinctions were noted in the emissions from the waste types. For example, the FSR waste appeared to have higher PCDD/PCDF emissions than the other three types, although waste-specific conclusions have to be tempered by the limited number of samples. Except for metals, MAGS emissions factors were significantly lower than other published data for an air curtain incinerator and a burn pile. Comparison of MAGS data

with previous data taken by the manufacturer shows higher emissions in the former, likely because the emissions sampling period included startups and partial shutdowns as well as steady state operation.

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Appendix A: CEM – Max, min, and average for each test

Table A1. CEM concentrations (Max, Min, Average, Standard deviation) for each waste run.

Waste Type		O ₂ Vol-%	CO ₂ Vol-%	CO ppm	CH ₄ ppm	H ₂ O Vol-%	HCl ppm	SO ₂ ppm	NO ppm	NO ₂ ppm	NO _x as NO ₂ ppm
SW-1	Max	17	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Min	4.0	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Average	8.1	NA	NA	NA	NA	NA	NA	NA	NA	NA
	STDV	2.2	NA	NA	NA	NA	NA	NA	NA	NA	NA
SW-2	Max	20	17	1,778	10	12	0.90	0.00	464	35	387
	Min	2.3	1.0	0.00	0.00	5.9	0.00	0.00	0.00	0.00	4.6
	Average	10.0	9.9	45	0.07	9.0	0.40	0.00	157	6.0	186
	STDV	2.7	2.7	151	0.69	1.8	0.19	0.00	117	6.4	70
SW-3	Max	17	17	6,612	1,526	13	1.3	15	527	29	430
	Min	0.14	1.2	0.00	0.00	2.2	0.00	0.00	0.00	0.0	7
	Average	8.9	9.9	91	9.0	9.9	0.51	0.09	189	6.7	206
	STDV	2.3	2.2	518	102	1.5	0.21	1.1	123	5.1	75
HP-1	Max	18	15	4,406	22	12	3.2	1.8	238	26	224
	Min	3.4	0.30	0.06	0.00	5.2	0.00	0.00	0.00	0.00	2.2
	Average	9.0	9.2	57	0.19	8.9	0.45	0.01	96	5.3	147
	STDV	2.0	2.1	314	1.7	1.5	0.50	0.14	83	3.3	38
HP-2	Max	14	16	19,181	138	12	1.2	1.3	220	21	207
	Min	3.0	5.4	0.00	0.00	7.6	0.18	0.00	0.00	0.19	83
	Average	8.9	9.6	144	1.3	9.9	0.70	0.01	78.6	3.4	140
	STDV	1.7	1.7	1535	11.9	1.1	0.21	0.10	73.8	2.6	25
KMC	Max	16	14	26,235	133	11	1.4	7.4	825	45	637
	Min	2.5	2.0	0.00	0.00	7.5	0.10	0.00	0.00	1.8	28
	Average	9.3	8.3	190	1.0	9.6	0.66	0.16	249	14	254
	STDV	2.8	2.1	1,733	11	0.70	0.28	0.70	194	9.5	132
FSR-1	Max	18	17	2,370	38	14	2.7	3.9	524	45	443
	Min	2.2	1.5	2.4	0.00	7.7	0.64	0.00	0.00	7.1	30
	Average	8.8	9.7	56	0.82	11.1	1.81	0.57	261	16	260
	STDV	2.3	2.3	174	3.0	1.4	0.31	0.94	113	5.7	69
FSR-2	Max	14	17	564	2.9	13	2.1	3.4	522	31	441
	Min	2.1	4.1	0.00	0.00	6.8	0.21	0.00	0.00	3.2	40
	Average	8.7	9.8	21	0.02	11.7	1.0	0.31	259	10	253
	STDV	1.9	2.0	58	0.23	1.3	0.3	0.72	110	4.3	68

NA – not analyzed.

Table A2. CEM emissions factors (carbon mass balance) for each waste run.

Waste Type	CO ₂	CO	CH ₄	HCl	SO ₂	NO	NO ₂	NO _x as NO ₂
	g/kg waste							
SW-2	1.4E+03	4.1E-01	3.4E-04	4.7E-03	ND	1.9E+00	9.0E-02	2.8E+00
SW-3	1.4E+03	8.2E-01	5.6E-03	6.0E-03	3.4E-04	2.1E+00	1.0E-01	3.0E+00
HP-1	1.8E+03	7.3E-01	1.4E-03	7.5E-03	2.1E-04	2.0E+00	1.1E-01	3.1E+00
HP-2	1.8E+03	1.8E+00	9.2E-03	1.1E-02	1.2E-04	1.9E+00	6.9E-02	2.8E+00
KMC	1.7E+03	2.5E+00	7.8E-03	1.1E-02	2.5E-03	3.9E+00	3.0E-01	5.5E+00
FSR-1	1.9E+03	7.1E-01	5.8E-03	2.9E-02	8.1E-03	3.7E+00	3.4E-01	5.3E+00
FSR-2	1.9E+03	2.6E-01	1.6E-04	1.6E-02	4.4E-03	3.6E+00	2.0E-01	5.1E+00

ND – not detected.

Appendix B: PM – Full data set

Table B1. PM concentrations and EF for each of the test runs, Method 5 (glass fiber filter).

Waste Type	Concentration mg PM/m³ at 7% O₂	EF^a g/kg waste	EF g/kg waste input
SW-1	42	NA	0.28
SW-2	32	0.19	0.23
SW-3	42	0.26	0.29
HP-1	38	0.35	0.37
HP-2	45	0.43	0.61
KMC	18	0.17	0.13
FSR-1	51	0.59	0.38
FSR-2	69	0.65	0.69

NA – not applicable. ^a Carbon mass balance method.

Table B2. PM concentrations and EF for each of the test runs, Modified Method 5 (Teflon filter).

Waste Type	Concentration mg PM/m³ at 7% O₂	EF^a g/kg waste	EF g/kg waste input
SW-2	41	0.24	0.21
SW-3	35	0.36	0.24
HP-1	28	0.26	0.26
HP-2	41	0.23	0.56
KMC	16	0.15	0.12
FSR-1	11	0.13	0.084
FSR-2	15	0.11	0.090

Appendix C: Metals – Full data set

Table C1. Metal concentrations in each of the runs, ICP analyzes.

Element	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
$\mu\text{g}/\text{m}^3$ at 7% O_2								
Sodium (Na)	2.1E+03	4.7E+03	2.2E+03	4.4E+03	7.3E+03	2.9E+03	1.9E+03	3.0E+03
Iron (Fe)	3.8E+01	8.5E+01	1.2E+01	3.6E+01	8.6E+01	5.4E+00	1.9E+01	6.2E+01
Copper (Cu)	1.7E+02	2.0E+02	8.4E+01	1.2E+02	2.2E+02	7.0E+01	1.3E+02	2.2E+02
Cadmium (Cd)	6.9E-01	1.7E+00	7.7E-01	5.7E-01	4.2E-01	3.7E-01	<MDL	<MDL
Lead (Pb)	9.9E+01	2.1E+02	5.6E+01	9.4E+01	7.2E+01	3.2E+01	7.3E+01	4.9E+01

MDL – method detection limit. ICP - inductively coupled plasma spectroscopy.

Table C2. Metal concentrations in each of the runs, XRF analyzes.

Element	SW-3	HP-2	KMC	FSR-1
$\mu\text{g}/\text{m}^3$ at 7% O_2				
Sodium (Na)	1.5E+03 [#]	ND	2.4E+03	3.4E+02 [#]
Magnesium (Mg)	1.1E+02 [#]	1.5E+02 [#]	1.1E+02	3.0E+01
Aluminum (Al)	8.6E+00 [#]	ND	2.9E+00 [#]	ND
Silica (Si)	2.9E+01	8.4E+01	2.7E+02	3.8E+01
Phosphorous (P)	1.8E+00 [#]	1.6E+01	4.9E+00	3.3E+01
Sulfur (S)	1.5E+02	3.0E+02	3.0E+02	4.2E+01
Chloride (Cl)	3.6E+03	5.7E+03	4.0E+03	9.9E+02
Potassium (K)	1.2E+03	1.8E+03	1.6E+03	3.5E+02
Calcium (Ca)	ND	3.4E+02	ND	ND
Titanium (Ti)	5.7E-01 [#]	1.7E+00	1.4E+00	1.2E-01 [#]
Vanadium (V)	8.1E-01	7.5E-01 [#]	1.6E+00	9.3E-02 [#]
Chromium (Cr)	6.7E+00	1.9E+01	7.0E+00	1.8E+01
Manganese (Mn)	2.2E+00	1.2E+01	1.7E+00	8.9E-01
Iron (Fe)	1.3E+01	8.5E+01	4.7E+00 [#]	1.5E+01
Cobalt (Co)	2.0E+00	5.9E+00	3.5E-01 [#]	4.1E-01
Nickel (Ni)	2.2E+00	1.5E+01	7.0E-01 [#]	4.4E-01
Copper (Cu)	7.7E+01	2.3E+02	6.6E+01	9.9E+01
Zink (Zn)	9.1E+02	2.2E+03	2.5E+02	1.9E+02
Gallium (Ga)	1.3E-01 [#]	ND	2.5E-01 [#]	1.5E-01 [#]
Germanium (Ge)	ND	ND	6.7E-02 [#]	ND
Arsenic (As)	ND	ND	5.4E-01 [#]	4.0E-01 [#]
Selenium (Se)	1.6E+00	2.8E+00	1.0E+00	4.5E-01
Bromine (Br)	3.5E+00	3.3E+00	7.1E+00	2.0E+00
Rubidium (Rb)	3.2E+00	8.1E+00	4.6E+00	8.8E-01

Strontium (Sr)	1.8E-01	2.5E+00	1.5E-01 [#]	1.3E-01
Yttrium (Y)	2.2E-01	5.6E-01	5.7E-02 [#]	1.1E-01
Zirconium (Zr)	1.4E-01 [#]	ND	9.1E-02 [#]	ND
Molybdenum (Mo)	1.9E+01	4.1E+01	8.7E+01	1.9E+01
Palladium (Pd)	1.0E-01 [#]	1.0E-01 [#]	ND	5.7E-02 [#]
Silver (Ag)	4.2E+00	7.9E+01	5.0E+00 [#]	7.6E-01
Cadmium (Cd)	7.1E-01	8.6E-01 [#]	2.6E-01 [#]	2.7E-01 [#]
Indium (In)	1.9E-01 [#]	ND	4.2E-02 [#]	ND
Tin (Sn)	1.9E+02	1.9E+02	1.4E+01	2.1E+01
Antimony (Sb)	5.1E+01	7.0E+01	8.5E+00	3.4E+01
Barium (Ba)	1.1E+00 [#]	1.2E+00 [#]	3.1E+00	ND
Lanthanum (La)	2.7E-01 [#]	1.5E+00 [#]	2.4E+00	1.8E-01 [#]
Mercury (Hg)	ND	ND	ND	ND
Lead (Pb)	5.2E+01	1.2E+02	3.1E+01	3.7E+01

ND – not detected. # Less than three times the uncertainty.

XRF - X-ray Fluorescence Spectrometry

Table C3. Metal emissions factors (carbon mass balance method) in each of the runs, ICP analyzes.

Element	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	mg/kg waste						
Sodium (Na)	2.8E+01	2.3E+01	4.1E+01	4.0E+01	2.7E+01	2.3E+01	2.1E+01
Iron (Fe)	5.0E-01	1.2E-01	3.4E-01	4.8E-01	5.1E-02	2.3E-01	4.4E-01
Copper (Cu)	1.2E+00	8.7E-01	1.1E+00	1.2E+00	6.6E-01	1.6E+00	1.6E+00
Cadmium (Cd)	9.8E-03	8.0E-03	5.3E-03	2.3E-03	3.5E-03	<MDL	<MDL
Lead (Pb)	1.3E+00	5.8E-01	8.7E-01	4.0E-01	3.0E-01	8.8E-01	3.5E-01

MDL – method detection limit. ICP - inductively coupled plasma spectroscopy.

Table C4. Metal emissions factors (carbon mass balance method) in each of the runs, XRF analyses.

Element	SW-3	HP-2	KMC	FSR-1
	mg/kg waste			
Sodium (Na)	1.5E+01 [#]	ND	2.3E+01	4.1E+00 [#]
Magnesium (Mg)	1.1E+00 [#]	8.5E-01 [#]	1.0E+00	3.6E-01
Aluminum (Al)	9.0E-02 [#]	ND	2.8E-02 [#]	ND
Silica (Si)	3.0E-01	4.7E-01	2.5E+00	4.6E-01
Phosphorous (P)	1.8E-02 [#]	8.8E-02	4.6E-02	4.0E-01
Sulfur (S)	1.6E+00	1.7E+00	2.8E+00	5.1E-01
Chloride (Cl)	3.8E+01	3.2E+01	3.8E+01	1.2E+01
Potassium (K)	1.2E+01	1.0E+01	1.5E+01	4.3E+00
Calcium (Ca)	ND	1.9E+00	ND	ND

Titanium (Ti)	5.9E-03 [#]	9.3E-03	1.4E-02	1.5E-03 [#]
Vanadium (V)	8.4E-03	4.2E-03 [#]	1.5E-02	1.1E-03 [#]
Chromium (Cr)	6.9E-02	1.0E-01	6.6E-02	2.2E-01
Manganese (Mn)	2.3E-02	6.6E-02	1.6E-02	1.1E-02
Iron (Fe)	1.4E-01	4.7E-01	4.5E-02	1.8E-01
Cobalt (Co)	2.0E-02	3.3E-02	3.3E-03	4.9E-03
Nickel (Ni)	2.3E-02	8.5E-02	6.6E-03	5.3E-03
Copper (Cu)	8.0E-01	1.3E+00	6.3E-01	1.2E+00
Zink (Zn)	9.5E+00	1.2E+01	2.4E+00	2.4E+00
Gallium (Ga)	1.4E-03 [#]	ND	2.4E-03	1.8E-03 [#]
Germanium (Ge)	ND	ND	6.3E-04 [#]	ND
Arsenic (As)	ND	ND	5.1E-03 [#]	4.8E-03 [#]
Selenium (Se)	1.7E-02	1.6E-02	9.4E-03	5.4E-03
Bromine (Br)	3.6E-02	1.8E-02	6.7E-02	2.5E-02
Rubidium (Rb)	3.3E-02	4.5E-02	4.4E-02	1.1E-02
Strontium (Sr)	1.8E-03	1.4E-02	1.4E-03	1.5E-03
Yttrium (Y)	2.3E-03	3.1E-03	5.3E-04 [#]	1.3E-03
Zirconium (Zr)	1.5E-03 [#]	ND	8.6E-04 [#]	ND
Molybdenum (Mo)	2.0E-01	2.3E-01	8.2E-01	2.3E-01
Palladium (Pd)	1.1E-03 [#]	5.8E-04 [#]	ND	7.0E-04 [#]
Silver (Ag)	4.4E-02	4.4E-01	4.7E-02	9.2E-03
Cadmium (Cd)	7.4E-03	4.8E-03 [#]	2.4E-03 [#]	3.3E-03 [#]
Indium (In)	1.9E-03 [#]	ND	4.0E-04 [#]	ND
Tin (Sn)	1.9E+00	1.0E+00	1.3E-01	2.6E-01
Antimony (Sb)	5.3E-01	3.9E-01	8.0E-02	4.1E-01
Barium (Ba)	1.1E-02 [#]	6.8E-03 [#]	2.9E-02	ND
Lanthanum (La)	2.8E-03 [#]	8.5E-03 [#]	2.3E-02	2.2E-03 [#]
Mercury (Hg)	ND	ND	ND	ND
Lead (Pb)	5.4E-01	6.9E-01	2.9E-01	4.4E-01

ND – not detected. # Less than three times the uncertainty.

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Table C5. Metal emissions factors (waste input) in each of the runs, ICP analyzes.

Element	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
mg/kg waste input							
Sodium (Na)	2.4E+01	1.5E+01	4.1E+01	1.0E+02	2.1E+01	1.4E+01	1.8E+01
Iron (Fe)	4.3E-01	8.2E-02	3.4E-01	1.2E+00	3.9E-02	1.4E-01	3.7E-01
Copper (Cu)	1.0E+00	5.8E-01	1.1E+00	3.0E+00	5.0E-01	9.8E-01	1.3E+00
Cadmium (Cd)	8.5E-03	5.3E-03	5.4E-03	5.7E-03	2.6E-03	<MDL	<MDL
Lead (Pb)	1.1E+00	3.9E-01	8.8E-01	9.9E-01	2.3E-01	5.5E-01	3.0E-01

MDL – method detection limit. ICP - inductively coupled plasma spectroscopy.

Table C6. Metal emissions factors (waste input) in each of the runs, XRF analyzes.

Element	SW-3	HP-2	KMC	FSR-1
mg/kg waste				
Sodium (Na)	1.0E+01 [#]	ND	1.7E+01	2.6E+00 [#]
Magnesium (Mg)	7.6E-01 [#]	2.1E+00 [#]	8.0E-01	2.3E-01
Aluminum (Al)	6.0E-02 [#]	ND	2.1E-02 [#]	ND
Silica (Si)	2.0E-01	1.2E+00	1.9E+00	2.9E-01
Phosphorous (P)	1.2E-02 [#]	2.2E-01	3.5E-02	2.5E-01
Sulfur (S)	1.1E+00	4.1E+00	2.1E+00	3.2E-01
Chloride (Cl)	2.5E+01	7.8E+01	2.9E+01	7.5E+00
Potassium (K)	8.0E+00	2.5E+01	1.1E+01	2.7E+00
Calcium (Ca)	ND	4.6E+00	ND	ND
Titanium (Ti)	3.9E-03 [#]	2.3E-02	1.0E-02	9.4E-04 [#]
Vanadium (V)	5.6E-03	1.0E-02 [#]	1.1E-02	7.1E-04 [#]
Chromium (Cr)	4.6E-02	2.6E-01	5.1E-02	1.4E-01
Manganese (Mn)	1.5E-02	1.6E-01	1.3E-02	6.8E-03
Iron (Fe)	9.3E-02	1.2E+00	3.4E-02	1.1E-01
Cobalt (Co)	1.4E-02	8.1E-02	2.5E-03	3.1E-03
Nickel (Ni)	1.5E-02	2.1E-01	5.0E-03	3.3E-03
Copper (Cu)	5.3E-01	3.1E+00	4.8E-01	7.5E-01
Zink (Zn)	6.3E+00	3.0E+01	1.8E+00	1.5E+00
Gallium (Ga)	9.1E-04 [#]	ND	1.8E-03	1.1E-03 [#]
Germanium (Ge)	ND	ND	4.8E-04 [#]	ND
Arsenic (As)	ND	ND	3.9E-03 [#]	3.0E-03 [#]
Selenium (Se)	1.1E-02	3.9E-02	7.1E-03	3.4E-03
Bromine (Br)	2.4E-02	4.5E-02	5.1E-02	1.5E-02
Rubidium (Rb)	2.2E-02	1.1E-01	3.3E-02	6.7E-03
Strontium (Sr)	1.2E-03	3.5E-02	1.1E-03	9.7E-04
Yttrium (Y)	1.5E-03	7.7E-03	4.1E-04 [#]	8.3E-04
Zirconium (Zr)	9.9E-04 [#]	ND	6.5E-04 [#]	ND
Molybdenum (Mo)	1.3E-01	5.6E-01	6.2E-01	1.5E-01
Palladium (Pd)	7.0E-04 [#]	1.4E-03 [#]	ND	4.4E-04 [#]
Silver (Ag)	2.9E-02	1.1E+00	3.6E-02	5.8E-03
Cadmium (Cd)	4.9E-03	1.2E-02 [#]	1.9E-03 [#]	2.0E-03 [#]
Indium (In)	1.3E-03 [#]	ND	3.0E-04 [#]	ND
Tin (Sn)	1.3E+00	2.5E+00	1.0E-01	1.6E-01
Antimony (Sb)	3.5E-01	9.6E-01	6.1E-02	2.6E-01
Barium (Ba)	7.5E-03 [#]	1.7E-02 [#]	2.2E-02	ND
Lanthanum (La)	1.9E-03 [#]	2.1E-02 [#]	1.7E-02	1.4E-03 [#]
Mercury (Hg)	ND	ND	ND	ND
Lead (Pb)	3.6E-01	1.7E+00	2.2E-01	2.8E-01

ND – not detected. # Less than three times the uncertainty.

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Table C7. Metal concentration in each of the test runs in mg metal/g particles, ICP analyzes.

Element	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
mg metal/g particles								
Sodium (Na)	1.5E+02	1.2E+02	6.3E+01	1.6E+02	1.8E+02	1.8E+02	1.7E+02	2.0E+02
Iron (Fe)	2.7E+00	2.1E+00	3.4E-01	1.3E+00	2.1E+00	3.4E-01	1.7E+00	4.2E+00
Copper (Cu)	1.2E+01	4.9E+00	2.4E+00	4.3E+00	5.4E+00	4.3E+00	1.2E+01	1.5E+01
Cadmium (Cd)	4.8E-02	4.1E-02	2.2E-02	2.1E-02	1.0E-02	2.3E-02	<MDL	<MDL
Lead (Pb)	7.0E+00	5.2E+00	1.6E+00	3.4E+00	1.8E+00	2.0E+00	6.6E+00	3.3E+00

MDL – method detection limit. ICP - inductively coupled plasma spectroscopy.

Table C8. Metal concentration in each of the test runs in mg metal/g particles, XRF analyzes.

Element	SW-3	HP-2	KMC	FSR-1
mg metal/g particles				
Sodium (Na)	4.2E+01 [#]	ND	1.5E+02	3.1E+01 [#]
Magnesium (Mg)	3.1E+00 [#]	3.7E+00 [#]	6.9E+00	2.7E+00
Aluminum (Al)	2.5E-01 [#]	ND	1.8E-01 [#]	ND
Silica (Si)	8.2E-01	2.1E+00	1.7E+01	3.5E+00
Phosphorous (P)	5.1E-02 [#]	3.9E-01	3.0E-01	3.0E+00
Sulfur (S)	4.4E+00	7.3E+00	1.9E+01	3.8E+00
Chloride (Cl)	1.0E+02	1.4E+02	2.5E+02	9.0E+01
Potassium (K)	3.3E+01	4.4E+01	9.7E+01	3.2E+01
Calcium (Ca)	ND	8.3E+00	ND	ND
Titanium (Ti)	1.6E-02 [#]	4.1E-02	8.9E-02	1.1E-02 [#]
Vanadium (V)	2.3E-02	1.9E-02 [#]	9.9E-02	8.5E-03 [#]
Chromium (Cr)	1.9E-01	4.6E-01	4.4E-01	1.7E+00
Manganese (Mn)	6.3E-02	2.9E-01	1.1E-01	8.1E-02
Iron (Fe)	3.8E-01	2.1E+00	2.9E-01	1.3E+00
Cobalt (Co)	5.6E-02	1.4E-01	2.2E-02	3.7E-02
Nickel (Ni)	6.3E-02	3.8E-01	4.3E-02	4.0E-02
Copper (Cu)	2.2E+00	5.6E+00	4.1E+00	9.0E+00
Zinc (Zn)	2.6E+01	5.4E+01	1.5E+01	1.8E+01
Gallium (Ga)	3.8E-03 [#]	ND	1.6E-02	1.4E-02 [#]
Germanium (Ge)	ND	ND	4.1E-03 [#]	ND
Arsenic (As)	ND	ND	3.4E-02 [#]	3.6E-02 [#]
Selenium (Se)	4.7E-02	7.0E-02	6.2E-02	4.1E-02
Bromine (Br)	9.9E-02	8.1E-02	4.4E-01	1.8E-01
Rubidium (Rb)	9.2E-02	2.0E-01	2.9E-01	8.0E-02
Strontium (Sr)	5.1E-03	6.2E-02	9.1E-03	1.2E-02
Yttrium (Y)	6.3E-03	1.4E-02	3.5E-03 [#]	9.9E-03
Zirconium (Zr)	4.1E-03 [#]	ND	5.6E-03 [#]	ND
Molybdenum (Mo)	5.4E-01	1.0E+00	5.4E+00	1.8E+00

Palladium (Pd)	2.9E-03 [#]	2.6E-03 [#]	ND	5.2E-03 [#]
Silver (Ag)	1.2E-01	1.9E+00	3.1E-01	6.9E-02
Cadmium (Cd)	2.0E-02	2.1E-02 [#]	1.6E-02 [#]	2.4E-02 [#]
Indium (In)	5.3E-03 [#]	ND	2.6E-03 [#]	ND
Tin (Sn)	5.3E+00	4.5E+00	8.7E-01	2.0E+00
Antimony (Sb)	1.5E+00	1.7E+00	5.3E-01	3.1E+00
Barium (Ba)	3.1E-02 [#]	3.0E-02 [#]	1.9E-01	ND
Lanthanum (La)	7.8E-03 [#]	3.8E-02 [#]	1.5E-01	1.6E-02 [#]
Mercury (Hg)	ND	ND	ND	ND
Lead (Pb)	1.5E+00	3.0E+00	1.9E+00	3.3E+00

ND – not detected. [#] Less than three times the uncertainty. XRF - X-ray Fluorescence Spectrometry

Table C9. Metals in ash.

Metal	SW-1	SW-2	SW-3	HP	KMC	FSR
g Metal/kg ash						
Carbon (C)	420	362	450	270	331	331
Oxygen (O)	192	194	169	217	213	198
Calcium (Ca)	166	176	166	297	156	171
Chloride (Cl)	49	95	75	75	72	96
Aluminum (Al)	42	33	33	33	38	64
Silica (Si)	37	40	32	27	43	30
Sodium (Na)	24	19	14	13	70	43
Iron (Fe)	16	24	14	16	6.0	24
Magnesium (Mg)	11	8.2	7.5	11	8.1	7.0
Zink (Zn)	10	13	11	10	5.2	17
Potassium (K)	9.7	11	9.2	5.2	25	17
Titanium (Ti)	5.3	5.0	4.9	6.9	13	16
Phosphorous (P)	4.9	7.5	3.5	3.2	9.7	8.0
Sulfur (S)	4.4	4.3	4.3	3.3	4.8	5.6
Chromium (Cr)	2.3	2.1	0.65	2.4	0.63	0.45
Copper (Cu)	1.2	0.85	0.52	1.8	0.88	1.0
Manganese (Mn)	1.3	1.4	0.85	1.0	0.31	0.53
Hydrogen (H)	1.2	1.2	1.1	2.8	1.1	1.0
Nickel (Ni)	1.0	1.0	0.33	1.0	0.34	0.21
Molybdenum (Mo)	0.33	0.32	0.14	0.42	0.15	ND
Barium (Ba)	0.42	0.49	0.58	0.55	0.79	ND
Tin (Sn)	0.35	0.48	0.58	0.36	0.14	ND
Zirconium (Zr)	0.21	0.20	0.14	0.13	0.18	0.12
Strontium (Sr)	0.18	0.20	0.21	0.25	0.19	0.49
Bromine (Br)	0.14	0.060	0.075	0.055	0.075	0.070
Lead (Pb)	0.15	0.28	0.18	0.23	0.11	0.18

Cobalt (Co)	0.080	ND	ND	0.43	ND	ND
Niobium (Nb)	0.020	ND	ND	ND	ND	ND

ND – not detected.

Appendix D: VOCs – Full data set

Table D1. VOC concentrations in the three standard waste runs.

Compound	SW-1		SW-2		SW-3	
	Con.	Method detection limit	Con.	Method detection limit	Con.	Method detection limit
	$\mu\text{g}/\text{m}^3$ at 7% O_2					
Propene	6.4E+01	3.7E-01	6.3E+01	3.4E-01	9.1E+01	1.8E+01
Dichlorodifluoromethane (CFC 12)	6.1E-01 [#]	4.6E-01	ND	4.2E-01	ND	2.1E+01
Chloromethane*	1.1E+01	4.0E-01	3.1E+00	3.6E-01	2.2E+01 [#]	1.9E+01
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	5.1E-01	ND	4.6E-01	ND	2.4E+01
Vinyl Chloride*	2.2E+01	4.6E-01	6.1E+00	4.2E-01	ND	2.1E+01
1,3-Butadiene*	ND	6.0E-01	ND	5.3E-01	ND	2.7E+01
Bromomethane*	3.0E+00	5.1E-01	1.7E+00	4.6E-01	ND	2.4E+01
Chloroethane*	8.4E-01 [#]	4.6E-01	ND	4.2E-01	ND	2.1E+01
Ethanol	7.6E+00	2.1E+00	5.0E+00 [#]	2.0E+00	ND	9.8E+01
Acetonitrile	ND	4.8E-01	ND	4.3E-01	ND	2.2E+01
Acrolein*	2.5E+01	4.6E-01	2.9E+01	4.2E-01	2.2E+01 [#]	2.1E+01
Acetone	3.7E+02	2.1E+00	2.4E+02	1.8E+00	ND	9.4E+01
Trichlorofluoromethane	ND	4.6E-01	ND	4.2E-01	ND	2.1E+01
2-Propanol (Isopropyl Alcohol)	1.9E+01	1.1E+00	4.5E+01	1.0E+00	ND	5.2E+01
Acrylonitrile*	1.0E+01	4.6E-01	3.8E+00	4.2E-01	ND	2.1E+01
1,1-Dichloroethene	ND	4.6E-01	ND	4.2E-01	ND	2.1E+01
Methylene Chloride*	6.6E+00	4.6E-01	1.7E+00	4.2E-01	ND	2.1E+01
3-Chloro-1-propene (Allyl Chloride)*	3.0E+01	4.3E-01	2.5E+00	3.9E-01	ND	2.0E+01
Trichlorotrifluoroethane	ND	4.6E-01	ND	4.2E-01	ND	2.1E+01
Carbon Disulfide*	2.5E+00	4.0E-01	1.7E+00	3.6E-01	5.2E+01 [#]	1.9E+01
trans-1,2-Dichloroethene	ND	5.1E-01	ND	4.6E-01	ND	2.4E+01
1,1-Dichloroethane	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
Methyl tert-Butyl Ether	ND	4.6E-01	ND	4.2E-01	ND	2.1E+01
Vinyl Acetate*	2.8E+01	1.8E+00	2.4E+01	1.5E+00	ND	8.0E+01
2-Butanone (MEK)	1.4E+01	5.7E-01	1.5E+01	5.2E-01	ND	2.6E+01
cis-1,2-Dichloroethene	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
Ethyl Acetate	ND	9.4E-01	ND	8.5E-01	ND	4.2E+01
n-Hexane	ND	4.0E-01	ND	3.6E-01	ND	1.9E+01
Chloroform*	2.4E+00	4.6E-01	6.8E-01 [#]	4.2E-01	ND	2.1E+01
Tetrahydrofuran (THF)	9.7E-01 [#]	5.4E-01	ND	4.9E-01	ND	2.5E+01
1,2-Dichloroethane*	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
1,1,1-Trichloroethane*	ND	4.6E-01	ND	4.2E-01	ND	2.1E+01
Benzene*	9.4E+01	4.3E-01	8.5E+01	3.9E-01	1.3E+04	7.9E+01
Carbon Tetrachloride*	ND	4.0E-01	ND	3.6E-01	ND	1.9E+01
Cyclohexane	ND	7.8E-01	ND	7.0E-01	ND	3.5E+01

1,2-Dichloropropane	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
Bromodichloromethane	8.5E-01 [#]	4.0E-01	ND	3.6E-01	ND	1.9E+01
Trichloroethene	ND	3.7E-01	ND	3.4E-01	ND	1.8E+01
1,4-Dioxane	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
Methyl Methacrylate*	ND	8.4E-01	ND	7.5E-01	ND	3.8E+01
n-Heptane	8.8E-01 [#]	4.6E-01	4.7E+00	4.2E-01	ND	2.1E+01
cis-1,3-Dichloropropene	2.7E+00	3.7E-01	ND	3.4E-01	ND	1.8E+01
4-Methyl-2-pentanone	1.4E+00	4.3E-01	5.4E-01 [#]	3.9E-01	ND	2.0E+01
trans-1,3-Dichloropropene	3.1E+00	4.3E-01	ND	3.9E-01	ND	2.0E+01
1,1,2-Trichloroethane	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
Toluene*	1.0E+01	4.6E-01	6.8E+00	4.2E-01	2.4E+02	2.1E+01
2-Hexanone	ND	4.3E-01	1.8E+00	3.9E-01	ND	2.0E+01
Dibromochloromethane	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
1,2-Dibromoethane	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
n-Butyl Acetate	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
n-Octane	2.1E+00	4.8E-01	2.1E+00	4.3E-01	ND	2.2E+01
Tetrachloroethene	ND	3.7E-01	ND	3.4E-01	ND	1.8E+01
Chlorobenzene*	1.0E+01	4.3E-01	3.1E+00	3.9E-01	ND	2.0E+01
Ethylbenzene	1.2E+00 [#]	4.3E-01	9.1E-01 [#]	3.9E-01	ND	2.0E+01
m,p-Xylenes*	1.9E+00 [#]	8.1E-01	7.5E-01 [#]	7.3E-01	ND	3.6E+01
Bromoform	ND	4.0E-01	ND	3.6E-01	ND	1.9E+01
Styrene*	ND	4.0E-01	ND	3.6E-01	ND	1.9E+01
o-Xylene*	7.9E-01 [#]	4.0E-01	4.7E-01 [#]	3.6E-01	ND	1.9E+01
n-Nonane	5.2E-01 [#]	4.0E-01	7.0E-01 [#]	3.6E-01	ND	1.9E+01
1,1,2,2-Tetrachloroethane	ND	4.0E-01	ND	3.6E-01	ND	1.9E+01
Cumene*	ND	4.0E-01	ND	3.6E-01	ND	1.9E+01
alpha-Pinene	ND	3.7E-01	ND	3.4E-01	ND	1.8E+01
n-Propylbenzene	4.5E-01 [#]	4.3E-01	ND	3.9E-01	ND	2.0E+01
4-Ethyltoluene	ND	4.3E-01	ND	3.9E-01	ND	2.0E+01
1,3,5-Trimethylbenzene	5.2E-01 [#]	4.3E-01	ND	3.9E-01	ND	2.0E+01
1,2,4-Trimethylbenzene	7.3E-01 [#]	4.0E-01	3.6E-01 [#]	3.6E-01	ND	1.9E+01
Benzyl Chloride*	7.6E+00	3.0E-01	7.8E-01 [#]	2.7E-01	ND	1.3E+01
1,3-Dichlorobenzene	1.9E+00	4.0E-01	7.0E-01 [#]	3.6E-01	ND	1.9E+01
1,4-Dichlorobenzene	8.2E-01 [#]	3.7E-01	ND	3.4E-01	ND	1.8E+01
1,2-Dichlorobenzene	2.7E+00	4.0E-01	1.2E+00	3.6E-01	ND	1.9E+01
d-Limonene	ND	3.7E-01	3.6E-01 [#]	3.4E-01	ND	1.8E+01
1,2-Dibromo-3-chloropropane	ND	2.7E-01	ND	2.4E-01	ND	1.2E+01
1,2,4-Trichlorobenzene	1.8E+00	4.3E-01	8.5E-01 [#]	3.9E-01	ND	2.0E+01
Naphthalene	1.2E+01	4.8E-01	1.4E+01	4.3E-01	4.7E+02	2.2E+01
Hexachlorobutadiene	ND	3.7E-01	ND	3.4E-01	ND	1.8E+01

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Table D2. VOC concentrations in each of the high plastic and KMC waste runs.

Compound	HP-1		HP-2		KMC	
	Con.	Method detection limit	Con.	Method detection limit	Con.	Method detection limit
	$\mu\text{g}/\text{m}^3$ at 7% O_2					
Propene	1.4E+02	8.7E-01	2.8E+00	2.7E-01	1.8E+01	1.1E+00
Dichlorodifluoromethane (CFC 12)	ND	1.1E+00	ND	3.3E-01	ND	1.3E+00
Chloromethane*	1.3E+01	9.3E-01	6.8E+00	3.0E-01	6.8E+00	1.1E+00
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	1.2E+00	ND	3.6E-01	ND	1.5E+00
Vinyl Chloride*	5.4E+01	1.1E+00	2.4E+00	3.3E-01	8.1E+00	1.3E+00
1,3-Butadiene*	ND	1.3E+00	ND	4.2E-01	ND	1.7E+00
Bromomethane*	ND	1.2E+00	4.9E-01 [#]	3.6E-01	ND	1.5E+00
Chloroethane*	6.5E+00	1.1E+00	ND	3.3E-01	ND	1.3E+00
Ethanol	ND	5.0E+00	ND	1.6E+00	ND	6.1E+00
Acetonitrile	1.0E+01	1.1E+00	9.7E+00	3.5E-01	1.0E+01	1.3E+00
Acrolein*	4.8E+01	1.1E+00	1.4E+00	3.3E-01	1.3E+01	1.3E+00
Acetone	ND	4.8E+00	1.6E+01	1.5E+00	4.3E+01	5.8E+00
Trichlorofluoromethane	ND	1.1E+00	ND	3.3E-01	ND	1.3E+00
2-Propanol (Isopropyl Alcohol)	ND	2.6E+00	ND	8.1E-01	ND	3.2E+00
Acrylonitrile*	1.7E+01	1.1E+00	1.1E+00	3.3E-01	7.2E+00	1.3E+00
1,1-Dichloroethene	ND	1.1E+00	ND	3.3E-01	ND	1.3E+00
Methylene Chloride*	2.3E+00 [#]	1.1E+00	2.0E+00	3.3E-01	5.6E+00	1.3E+00
3-Chloro-1-propene (Allyl Chloride)*	1.9E+00 [#]	9.9E-01	5.8E-01 [#]	3.1E-01	1.5E+00 [#]	1.2E+00
Trichlorotrifluoroethane	ND	1.1E+00	ND	3.3E-01	ND	1.3E+00
Carbon Disulfide*	2.4E+00 [#]	9.3E-01	1.3E+01	3.0E-01	2.1E+00 [#]	1.1E+00
trans-1,2-Dichloroethene	ND	1.2E+00	ND	3.6E-01	ND	1.5E+00
1,1-Dichloroethane	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
Methyl tert-Butyl Ether	ND	1.1E+00	ND	3.3E-01	ND	1.3E+00
Vinyl Acetate*	ND	4.1E+00	2.6E+00 [#]	1.3E+00	ND	5.0E+00
2-Butanone (MEK)	1.1E+01	1.3E+00	3.9E+00	4.1E-01	1.3E+01	1.6E+00
cis-1,2-Dichloroethene	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
Ethyl Acetate	ND	2.2E+00	ND	6.8E-01	ND	2.7E+00
n-Hexane	ND	9.3E-01	4.9E-01 [#]	3.0E-01	1.6E+00 [#]	1.1E+00
Chloroform*	2.5E+00 [#]	1.1E+00	2.4E+00	3.3E-01	ND	1.3E+00
Tetrahydrofuran (THF)	ND	1.2E+00	ND	3.9E-01	ND	1.5E+00
1,2-Dichloroethane*	2.9E+00 [#]	9.9E-01	ND	3.1E-01	ND	1.2E+00
1,1,1-Trichloroethane*	ND	1.1E+00	ND	3.3E-01	ND	1.3E+00
Benzene*	9.5E+02	6.0E+00	3.9E+02	3.1E+00	1.5E+03	1.2E+01
Carbon Tetrachloride*	ND	9.3E-01	ND	3.0E-01	ND	1.1E+00
Cyclohexane	ND	1.8E+00	ND	5.6E-01	ND	2.2E+00
1,2-Dichloropropane	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00

Bromodichloromethane	ND	9.3E-01	1.1E+00	3.0E-01	ND	1.1E+00
Trichloroethene	ND	8.7E-01	ND	2.7E-01	ND	1.1E+00
1,4-Dioxane	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
Methyl Methacrylate*	ND	1.9E+00	ND	6.0E-01	ND	2.3E+00
n-Heptane	ND	1.1E+00	4.9E-01 [#]	3.3E-01	ND	1.3E+00
cis-1,3-Dichloropropene	ND	8.7E-01	ND	2.7E-01	ND	1.1E+00
4-Methyl-2-pentanone	ND	9.9E-01	3.3E-01 [#]	3.1E-01	ND	1.2E+00
trans-1,3-Dichloropropene	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
1,1,2-Trichloroethane	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
Toluene*	2.3E+01	1.1E+00	8.4E+00	3.3E-01	6.4E+02	1.3E+01
2-Hexanone	1.1E+00 [#]	9.9E-01	ND	3.1E-01	3.9E+00	1.2E+00
Dibromochloromethane	ND	9.9E-01	2.2E+00	3.1E-01	ND	1.2E+00
1,2-Dibromoethane	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
n-Butyl Acetate	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
n-Octane	ND	1.1E+00	ND	3.5E-01	ND	1.3E+00
Tetrachloroethene	ND	8.7E-01	ND	2.7E-01	ND	1.1E+00
Chlorobenzene*	1.8E+01	9.9E-01	1.3E+00	3.1E-01	6.0E+00	1.2E+00
Ethylbenzene	7.3E+00	9.9E-01	ND	3.1E-01	2.2E+02	1.2E+00
m,p-Xylenes*	3.9E+00 [#]	1.9E+00	ND	5.8E-01	5.2E+01	2.3E+00
Bromoform	ND	9.3E-01	4.9E+00	3.0E-01	ND	1.1E+00
Styrene*	ND	9.3E-01	ND	3.0E-01	1.7E+00 [#]	1.1E+00
o-Xylene*	ND	9.3E-01	ND	3.0E-01	2.9E+01	1.1E+00
n-Nonane	ND	9.3E-01	ND	3.0E-01	ND	1.1E+00
1,1,2,2-Tetrachloroethane	ND	9.3E-01	ND	3.0E-01	ND	1.1E+00
Cumene*	ND	9.3E-01	ND	3.0E-01	7.5E+00	1.1E+00
alpha-Pinene	ND	8.7E-01	ND	2.7E-01	ND	1.1E+00
n-Propylbenzene	ND	9.9E-01	ND	3.1E-01	5.8E+00	1.2E+00
4-Ethyltoluene	ND	9.9E-01	ND	3.1E-01	ND	1.2E+00
1,3,5-Trimethylbenzene	ND	9.9E-01	ND	3.1E-01	2.9E+00 [#]	1.2E+00
1,2,4-Trimethylbenzene	ND	9.3E-01	ND	3.0E-01	5.2E+00	1.1E+00
Benzyl Chloride*	8.3E-01 [#]	6.8E-01	3.4E-01 [#]	2.2E-01	7.4E+00	8.4E-01
1,3-Dichlorobenzene	1.0E+00 [#]	9.3E-01	ND	3.0E-01	ND	1.1E+00
1,4-Dichlorobenzene	ND	8.7E-01	ND	2.7E-01	ND	1.1E+00
1,2-Dichlorobenzene	2.5E+00 [#]	9.3E-01	3.1E-01 [#]	3.0E-01	2.2E+00 [#]	1.1E+00
d-Limonene	ND	8.7E-01	ND	2.7E-01	ND	1.1E+00
1,2-Dibromo-3-chloropropane	ND	6.1E-01	ND	1.9E-01	ND	7.5E-01
1,2,4-Trichlorobenzene	ND	9.9E-01	4.1E-01 [#]	3.1E-01	ND	1.2E+00
Naphthalene	4.2E+00	1.1E+00	8.2E+01	3.5E-01	3.0E+02	1.3E+00
Hexachlorobutadiene	ND	8.7E-01	ND	2.7E-01	ND	1.1E+00

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Table D3. VOC concentrations in each of the FSR waste runs.

Compound	FSR-1		FSR-2	
	Con.	Method detection limit	Con.	Method detection limit
	$\mu\text{g}/\text{m}^3$ at 7% O ₂			
Propene	4.4E+02	9.1E+00	4.3E+01	3.4E-01
Dichlorodifluoromethane (CFC 12)	ND	1.1E+00	ND	4.2E-01
Chloromethane*	9.6E+01	9.7E-01	6.0E+00	3.7E-01
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	1.3E+00	ND	4.6E-01
Vinyl Chloride*	6.7E+01	1.1E+00	7.8E+00	4.2E-01
1,3-Butadiene*	ND	1.4E+00	ND	5.4E-01
Bromomethane*	3.2E+00 [#]	1.3E+00	8.5E-01 [#]	4.6E-01
Chloroethane*	3.9E+00	1.1E+00	5.7E-01 [#]	4.2E-01
Ethanol	ND	5.2E+00	ND	1.9E+00
Acetonitrile	ND	1.2E+00	2.8E+01	4.5E-01
Acrolein*	2.3E+02	1.1E+00	2.5E+01	4.2E-01
Acetone	4.6E+02	4.9E+00	1.9E+02	1.9E+00
Trichlorofluoromethane	ND	1.1E+00	ND	4.2E-01
2-Propanol (Isopropyl Alcohol)	ND	2.7E+00	ND	1.0E+00
Acrylonitrile*	6.6E+01	1.1E+00	5.7E+00	4.2E-01
1,1-Dichloroethene	ND	1.1E+00	ND	4.2E-01
Methylene Chloride*	6.9E+00	1.1E+00	4.5E+00	4.2E-01
3-Chloro-1-propene (Allyl Chloride)*	2.7E+01	1.0E+00	1.8E+01	3.9E-01
Trichlorotrifluoroethane	ND	1.1E+00	ND	4.2E-01
Carbon Disulfide*	2.3E+00 [#]	9.7E-01	9.0E-01 [#]	3.7E-01
trans-1,2-Dichloroethene	ND	1.3E+00	ND	4.6E-01
1,1-Dichloroethane	ND	1.0E+00	ND	3.9E-01
Methyl tert-Butyl Ether	ND	1.1E+00	ND	4.2E-01
Vinyl Acetate*	1.5E+02	4.2E+00	8.4E+01	1.6E+00
2-Butanone (MEK)	2.1E+02	1.4E+00	1.8E+02	5.1E+00
cis-1,2-Dichloroethene	ND	1.0E+00	ND	3.9E-01
Ethyl Acetate	ND	2.2E+00	ND	8.5E-01
n-Hexane	8.2E+00	9.7E-01	1.1E+00 [#]	3.7E-01
Chloroform*	2.0E+00 [#]	1.1E+00	8.5E-01 [#]	4.2E-01
Tetrahydrofuran (THF)	5.8E+00	1.3E+00	ND	4.9E-01
1,2-Dichloroethane*	ND	1.0E+00	ND	3.9E-01
1,1,1-Trichloroethane*	ND	1.1E+00	ND	4.2E-01
Benzene*	2.1E+03	1.0E+01	1.3E+02	3.9E-01
Carbon Tetrachloride*	ND	9.7E-01	ND	3.7E-01
Cyclohexane	ND	1.9E+00	ND	7.2E-01

1,2-Dichloropropane	ND	1.0E+00	ND	3.9E-01
Bromodichloromethane	ND	9.7E-01	ND	3.7E-01
Trichloroethene	ND	9.1E-01	ND	3.4E-01
1,4-Dioxane	2.7E+00 [#]	1.0E+00	ND	3.9E-01
Methyl Methacrylate*	ND	2.0E+00	ND	7.6E-01
n-Heptane	8.1E+00	1.1E+00	1.3E+00	4.2E-01
cis-1,3-Dichloropropene	2.6E+00 [#]	9.1E-01	1.6E+00	3.4E-01
4-Methyl-2-pentanone	4.9E+00	1.0E+00	ND	3.9E-01
trans-1,3-Dichloropropene	2.5E+00 [#]	1.0E+00	2.1E+00	3.9E-01
1,1,2-Trichloroethane	ND	1.0E+00	ND	3.9E-01
Toluene*	2.2E+02	1.1E+00	5.2E+01	4.2E-01
2-Hexanone	2.5E+01	1.0E+00	3.9E+01	3.9E-01
Dibromochloromethane	ND	1.0E+00	ND	3.9E-01
1,2-Dibromoethane	ND	1.0E+00	ND	3.9E-01
n-Butyl Acetate	ND	1.0E+00	ND	3.9E-01
n-Octane	6.9E+00	1.2E+00	ND	4.5E-01
Tetrachloroethene	ND	9.1E-01	ND	3.4E-01
Chlorobenzene*	2.5E+01	1.0E+00	7.3E+00	3.9E-01
Ethylbenzene	7.2E+01	1.0E+00	1.8E+01	3.9E-01
m,p-Xylenes*	1.7E+01	1.9E+00	8.2E+00	7.3E-01
Bromoform	ND	9.7E-01	ND	3.7E-01
Styrene*	ND	9.7E-01	ND	3.7E-01
o-Xylene*	8.1E+00	9.7E-01	4.6E+00	3.7E-01
n-Nonane	3.2E+00	9.7E-01	ND	3.7E-01
1,1,2,2-Tetrachloroethane	ND	9.7E-01	ND	3.7E-01
Cumene*	3.8E+00	9.7E-01	8.7E-01 [#]	3.7E-01
alpha-Pinene	ND	9.1E-01	ND	3.4E-01
n-Propylbenzene	2.4E+00 [#]	1.0E+00	1.5E+00	3.9E-01
4-Ethyltoluene	ND	1.0E+00	ND	3.9E-01
1,3,5-Trimethylbenzene	2.2E+00 [#]	1.0E+00	1.2E+00	3.9E-01
1,2,4-Trimethylbenzene	ND	9.7E-01	4.9E+00	3.7E-01
Benzyl Chloride*	2.2E+01	7.1E-01	6.0E+00	2.7E-01
1,3-Dichlorobenzene	2.8E+00 [#]	9.7E-01	2.1E+00	3.7E-01
1,4-Dichlorobenzene	1.2E+00 [#]	9.1E-01	7.2E-01 [#]	3.4E-01
1,2-Dichlorobenzene	5.3E+00	9.7E-01	3.0E+00	3.7E-01
d-Limonene	ND	9.1E-01	ND	3.4E-01
1,2-Dibromo-3-chloropropane	ND	6.4E-01	ND	2.4E-01
1,2,4-Trichlorobenzene	2.6E+00 [#]	1.0E+00	2.4E+00	3.9E-01
Naphthalene	4.3E+02	1.2E+01	5.7E+01	4.5E-01
Hexachlorobutadiene	ND	9.1E-01	ND	3.4E-01

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Table D4. VOC concentrations in four 10 min samples from standard waste run 3.

Compound	SW-3 00:00 - 00:10		SW-3 00:11 - 00:30		SW-3 02:10 - 02:32		SW-3 03:09 - 03:39	
	Con.	MDL	Con.	MDL	Con.	MDL	Con.	MDL
$\mu\text{g}/\text{m}^3$ at 7% O_2								
Propene	4.2E+02	4.0E+00	1.7E+01	2.6E-01	1.1E+01	3.9E-01	3.5E+00	2.4E-01
Dichlorodifluoromethane (CFC 12)	ND	4.9E+00	6.1E-01 [#]	3.2E-01	1.0E+00 [#]	4.7E-01	ND	3.0E-01
Chloromethane*	3.3E+01	4.3E+00	7.1E+00	2.8E-01	5.2E+00	4.2E-01	6.4E-01	2.7E-01
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	5.4E+00	ND	3.6E-01	ND	5.3E-01	ND	3.4E-01
Vinyl Chloride*	3.4E+01	4.9E+00	4.8E+01	3.2E-01	1.2E+01	4.7E-01	7.9E-01 [#]	3.0E-01
1,3-Butadiene*	2.1E+01	6.3E+00	ND	4.1E-01	ND	6.0E-01	ND	3.8E-01
Bromomethane*	ND	5.4E+00	9.5E-01 [#]	3.6E-01	6.7E-01 [#]	5.3E-01	4.8E-01 [#]	3.4E-01
Chloroethane*	ND	4.9E+00	ND	3.2E-01	ND	4.7E-01	ND	3.0E-01
Ethanol	7.2E+01	2.3E+01	ND	1.5E+00	ND	2.3E+00	ND	1.4E+00
Acetonitrile	1.7E+01	5.2E+00	9.4E+00	3.4E-01	5.7E+01	4.9E-01	4.3E+00	3.1E-01
Acrolein*	3.2E+02	4.9E+00	2.2E+01	3.2E-01	6.6E+00	4.7E-01	2.4E+00	3.0E-01
Acetone	ND	2.1E+01	5.8E+01	1.4E+00	1.5E+02	2.1E+00	2.4E+01	1.4E+00
Trichlorofluoromethane	ND	4.9E+00	ND	3.2E-01	ND	4.7E-01	ND	3.0E-01
2-Propanol (Isopropyl Alcohol)	2.1E+02	1.2E+01	2.4E+01	7.9E-01	9.8E+00	1.2E+00	3.5E+00	7.4E-01
Acrylonitrile*	1.1E+01 [#]	4.9E+00	1.3E+01	3.2E-01	1.8E+01	4.7E-01	6.5E-01 [#]	3.0E-01
1,1-Dichloroethene	ND	4.9E+00	4.8E-01 [#]	3.2E-01	ND	4.7E-01	ND	3.0E-01
Methylene Chloride*	ND	4.9E+00	5.9E+00	3.2E-01	2.8E+00	4.7E-01	7.3E-01 [#]	3.0E-01
3-Chloro-1-propene (Allyl Chloride)*	ND	4.6E+00	2.7E+00	3.0E-01	7.4E-01 [#]	4.4E-01	4.4E-01 [#]	2.8E-01
Trichlorotrifluoroethane	ND	4.9E+00	ND	3.2E-01	ND	4.7E-01	ND	3.0E-01
Carbon Disulfide*	6.2E+00 [#]	4.3E+00	1.3E+00	2.8E-01	7.2E+01	4.2E-01	2.3E+01	2.7E-01
trans-1,2-Dichloroethene	ND	5.4E+00	ND	3.6E-01	ND	5.3E-01	ND	3.4E-01
1,1-Dichloroethane	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
Methyl tert-Butyl Ether	ND	4.9E+00	ND	3.2E-01	ND	4.7E-01	ND	3.0E-01
Vinyl Acetate*	3.7E+01 [#]	1.9E+01	4.6E+00	1.2E+00	ND	1.8E+00	2.9E+00 [#]	1.1E+00
2-Butanone (MEK)	2.3E+01	6.0E+00	7.9E+00	4.0E-01	2.9E+01	5.8E-01	5.3E+00	3.7E-01
cis-1,2-Dichloroethene	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
Ethyl Acetate	ND	1.0E+01	ND	6.6E-01	ND	9.7E-01	ND	6.1E-01
n-Hexane	ND	4.3E+00	6.8E-01 [#]	2.8E-01	2.3E+00	4.2E-01	1.2E+00	2.7E-01
Chloroform*	1.3E+01 [#]	4.9E+00	6.7E-01 [#]	3.2E-01	2.0E+01	4.7E-01	3.0E+00	3.0E-01
Tetrahydrofuran (THF)	ND	5.7E+00	4.0E-01 [#]	3.7E-01	1.1E+00 [#]	5.5E-01	ND	3.5E-01
1,2-Dichloroethane*	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
1,1,1-Trichloroethane*	ND	4.9E+00	ND	3.2E-01	ND	4.7E-01	ND	3.0E-01
Benzene*	2.9E+03	4.6E+00	2.4E+02	3.0E+00	2.8E+02	8.8E-01	7.1E+01	2.8E-01
Carbon Tetrachloride*	ND	4.3E+00	ND	2.8E-01	ND	4.2E-01	ND	2.7E-01
Cyclohexane	ND	8.3E+00	ND	5.4E-01	ND	8.1E-01	ND	5.1E-01

1,2-Dichloropropane	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
Bromodichloromethane	ND	4.3E+00	ND	2.8E-01	3.7E+00	4.2E-01	7.9E-01 [#]	2.7E-01
Trichloroethene	ND	4.0E+00	ND	2.6E-01	ND	3.9E-01	2.5E-01 [#]	2.4E-01
1,4-Dioxane	ND	4.6E+00	4.3E+00	3.0E-01	ND	4.4E-01	ND	2.8E-01
Methyl Methacrylate*	ND	8.9E+00	ND	5.8E-01	ND	8.6E-01	ND	5.4E-01
n-Heptane	ND	4.9E+00	1.0E+00	3.2E-01	3.1E+00	4.7E-01	2.7E+00	3.0E-01
cis-1,3-Dichloropropene	ND	4.0E+00	5.2E-01 [#]	2.6E-01	ND	3.9E-01	ND	2.4E-01
4-Methyl-2-pentanone	ND	4.6E+00	4.5E-01 [#]	3.0E-01	2.5E+00	4.4E-01	4.9E-01 [#]	2.8E-01
trans-1,3-Dichloropropene	ND	4.6E+00	4.9E-01 [#]	3.0E-01	ND	4.4E-01	ND	2.8E-01
1,1,2-Trichloroethane	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
Toluene*	8.7E+01	4.9E+00	2.6E+00	3.2E-01	8.6E+00	4.7E-01	2.3E+00	3.0E-01
2-Hexanone	ND	4.6E+00	1.5E+00	3.0E-01	2.8E+00	4.4E-01	1.3E+00	2.8E-01
Dibromochloromethane	ND	4.6E+00	ND	3.0E-01	8.1E-01 [#]	4.4E-01	4.5E-01 [#]	2.8E-01
1,2-Dibromoethane	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
n-Butyl Acetate	ND	4.6E+00	1.8E+00	3.0E-01	ND	4.4E-01	ND	2.8E-01
n-Octane	ND	5.2E+00	7.3E-01 [#]	3.4E-01	1.3E+00 [#]	4.9E-01	1.9E+00	3.1E-01
Tetrachloroethene	1.2E+03	4.0E+00	ND	2.6E-01	ND	3.9E-01	ND	2.4E-01
Chlorobenzene*	1.7E+01	4.6E+00	8.9E+00	3.0E-01	2.8E+00	4.4E-01	8.2E-01 [#]	2.8E-01
Ethylbenzene	2.0E+01	4.6E+00	7.0E-01 [#]	3.0E-01	6.3E-01 [#]	4.4E-01	3.1E-01 [#]	2.8E-01
m,p-Xylenes*	ND	8.6E+00	1.3E+00 [#]	5.7E-01	ND	8.3E-01	ND	5.3E-01
Bromoform	ND	4.3E+00	ND	2.8E-01	ND	4.2E-01	1.1E+00	2.7E-01
Styrene*	3.6E+01	4.3E+00	ND	2.8E-01	ND	4.2E-01	ND	2.7E-01
o-Xylene*	ND	4.3E+00	7.6E-01 [#]	2.8E-01	4.8E-01 [#]	4.2E-01	3.2E-01 [#]	2.7E-01
n-Nonane	ND	4.3E+00	2.8E-01 [#]	2.8E-01	ND	4.2E-01	9.7E-01	2.7E-01
1,1,2,2-Tetrachloroethane	ND	4.3E+00	ND	2.8E-01	ND	4.2E-01	ND	2.7E-01
Cumene*	ND	4.3E+00	ND	2.8E-01	ND	4.2E-01	ND	2.7E-01
alpha-Pinene	ND	4.0E+00	ND	2.6E-01	ND	3.9E-01	ND	2.4E-01
n-Propylbenzene	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
4-Ethyltoluene	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
1,3,5-Trimethylbenzene	ND	4.6E+00	ND	3.0E-01	ND	4.4E-01	ND	2.8E-01
1,2,4-Trimethylbenzene	ND	4.3E+00	3.4E-01 [#]	2.8E-01	ND	4.2E-01	ND	2.7E-01
Benzyl Chloride*	ND	3.2E+00	2.3E+00	2.1E-01	8.9E-01 [#]	3.0E-01	5.8E-01 [#]	2.0E-01
1,3-Dichlorobenzene	4.6E+00 [#]	4.3E+00	8.6E-01	2.8E-01	9.6E-01 [#]	4.2E-01	2.8E-01 [#]	2.7E-01
1,4-Dichlorobenzene	ND	4.0E+00	5.4E-01 [#]	2.6E-01	5.2E-01 [#]	3.9E-01	ND	2.4E-01
1,2-Dichlorobenzene	1.1E+01 [#]	4.3E+00	3.4E+00	2.8E-01	1.5E+00	4.2E-01	4.3E-01 [#]	2.7E-01
d-Limonene	ND	4.0E+00	3.6E-01 [#]	2.6E-01	ND	3.9E-01	3.6E-01 [#]	2.4E-01
1,2-Dibromo-3-chloropropane	ND	2.9E+00	ND	1.8E-01	ND	2.8E-01	ND	1.7E-01
1,2,4-Trichlorobenzene	6.6E+00 [#]	4.6E+00	8.6E-01 [#]	3.0E-01	1.6E+00	4.4E-01	4.3E-01 [#]	2.8E-01
Naphthalene	9.6E+01	5.2E+00	3.6E+01	3.4E-01	4.9E+02	1.0E+00	1.1E+02	3.1E-01
Hexachlorobutadiene	ND	4.0E+00	ND	2.6E-01	ND	3.9E-01	ND	2.4E-01

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Table D5. VOC emissions factors (carbon mass balance method) from the three standard waste runs.

Compound	SW-1		SW-2		SW-3	
	EF	Method detection limit	EF	Method detection limit	EF	Method detection limit
mg/kg waste						
Propene	4.2E-01	2.4E-03	4.4E-01	2.4E-03	2.0E+00	3.9E-01
Dichlorodifluoromethane (CFC 12)	4.0E-03 [#]	3.0E-03	ND	3.0E-03	ND	4.6E-01
Chloromethane*	7.4E-02	2.6E-03	2.2E-02	2.6E-03	4.9E-01 [#]	4.1E-01
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	3.3E-03	ND	3.2E-03	ND	5.2E-01
Vinyl Chloride*	1.5E-01	3.0E-03	4.3E-02	3.0E-03	ND	4.6E-01
1,3-Butadiene*	ND	3.9E-03	ND	3.7E-03	ND	5.9E-01
Bromomethane*	1.9E-02	3.3E-03	1.2E-02	3.2E-03	ND	5.2E-01
Chloroethane*	5.4E-03 [#]	3.0E-03	ND	3.0E-03	ND	4.6E-01
Ethanol	5.0E-02	1.4E-02	3.5E-02 [#]	1.4E-02	ND	2.1E+00
Acetonitrile	ND	3.1E-03	ND	3.1E-03	ND	4.9E-01
Acrolein*	1.7E-01	3.0E-03	2.1E-01	3.0E-03	4.9E-01 [#]	4.6E-01
Acetone	2.4E+00	1.4E-02	1.7E+00	1.3E-02	ND	2.1E+00
Trichlorofluoromethane	ND	3.0E-03	ND	3.0E-03	ND	4.6E-01
2-Propanol (Isopropyl Alcohol)	1.3E-01	7.4E-03	3.2E-01	7.2E-03	ND	1.1E+00
Acrylonitrile*	6.8E-02	3.0E-03	2.7E-02	3.0E-03	ND	4.6E-01
1,1-Dichloroethene	ND	3.0E-03	ND	3.0E-03	ND	4.6E-01
Methylene Chloride*	4.3E-02	3.0E-03	1.2E-02	3.0E-03	ND	4.6E-01
3-Chloro-1-propene (Allyl Chloride)*	1.9E-01	2.8E-03	1.8E-02	2.8E-03	ND	4.4E-01
Trichlorotrifluoroethane	ND	3.0E-03	ND	3.0E-03	ND	4.6E-01
Carbon Disulfide*	1.7E-02	2.6E-03	1.2E-02	2.6E-03	1.1E+00 [#]	4.1E-01
trans-1,2-Dichloroethene	ND	3.3E-03	ND	3.2E-03	ND	5.2E-01
1,1-Dichloroethane	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
Methyl tert-Butyl Ether	ND	3.0E-03	ND	3.0E-03	ND	4.6E-01
Vinyl Acetate*	1.8E-01	1.2E-02	1.7E-01	1.1E-02	ND	1.8E+00
2-Butanone (MEK)	9.2E-02	3.7E-03	1.1E-01	3.6E-03	ND	5.7E-01
cis-1,2-Dichloroethene	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
Ethyl Acetate	ND	6.1E-03	ND	6.0E-03	ND	9.3E-01
n-Hexane	ND	2.6E-03	ND	2.6E-03	ND	4.1E-01
Chloroform*	1.6E-02	3.0E-03	4.8E-03 [#]	3.0E-03	ND	4.6E-01
Tetrahydrofuran (THF)	6.3E-03 [#]	3.5E-03	ND	3.4E-03	ND	5.4E-01
1,2-Dichloroethane*	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
1,1,1-Trichloroethane*	ND	3.0E-03	ND	3.0E-03	ND	4.6E-01
Benzene*	6.1E-01	2.8E-03	6.0E-01	2.8E-03	2.8E+02	1.7E+00
Carbon Tetrachloride*	ND	2.6E-03	ND	2.6E-03	ND	4.1E-01

Cyclohexane	ND	5.1E-03	ND	4.9E-03	ND	7.7E-01
1,2-Dichloropropane	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
Bromodichloromethane	5.5E-03 [#]	2.6E-03	ND	2.6E-03	ND	4.1E-01
Trichloroethene	ND	2.4E-03	ND	2.4E-03	ND	3.9E-01
1,4-Dioxane	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
Methyl Methacrylate*	ND	5.4E-03	ND	5.3E-03	ND	8.3E-01
n-Heptane	5.7E-03 [#]	3.0E-03	3.3E-02	3.0E-03	ND	4.6E-01
cis-1,3-Dichloropropene	1.7E-02	2.4E-03	ND	2.4E-03	ND	3.9E-01
4-Methyl-2-pentanone	9.0E-03	2.8E-03	3.8E-03 [#]	2.8E-03	ND	4.4E-01
trans-1,3-Dichloropropene	2.0E-02	2.8E-03	ND	2.8E-03	ND	4.4E-01
1,1,2-Trichloroethane	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
Toluene*	6.6E-02	3.0E-03	4.8E-02	3.0E-03	5.2E+00	4.6E-01
2-Hexanone	ND	2.8E-03	1.3E-02	2.8E-03	ND	4.4E-01
Dibromochloromethane	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
1,2-Dibromoethane	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
n-Butyl Acetate	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
n-Octane	1.4E-02	3.1E-03	1.5E-02	3.1E-03	ND	4.9E-01
Tetrachloroethene	ND	2.4E-03	ND	2.4E-03	ND	3.9E-01
Chlorobenzene*	6.6E-02	2.8E-03	2.2E-02	2.8E-03	ND	4.4E-01
Ethylbenzene	7.9E-03 [#]	2.8E-03	6.4E-03 [#]	2.8E-03	ND	4.4E-01
m,p-Xylenes*	1.3E-02 [#]	5.2E-03	5.3E-03 [#]	5.1E-03	ND	8.0E-01
Bromoform	ND	2.6E-03	ND	2.6E-03	ND	4.1E-01
Styrene*	ND	2.6E-03	ND	2.6E-03	ND	4.1E-01
o-Xylene*	5.2E-03 [#]	2.6E-03	3.3E-03 [#]	2.6E-03	ND	4.1E-01
n-Nonane	3.4E-03 [#]	2.6E-03	4.9E-03 [#]	2.6E-03	ND	4.1E-01
1,1,2,2-Tetrachloroethane	ND	2.6E-03	ND	2.6E-03	ND	4.1E-01
Cumene*	ND	2.6E-03	ND	2.6E-03	ND	4.1E-01
alpha-Pinene	ND	2.4E-03	ND	2.4E-03	ND	3.9E-01
n-Propylbenzene	2.9E-03 [#]	2.8E-03	ND	2.8E-03	ND	4.4E-01
4-Ethyltoluene	ND	2.8E-03	ND	2.8E-03	ND	4.4E-01
1,3,5-Trimethylbenzene	3.4E-03 [#]	2.8E-03	ND	2.8E-03	ND	4.4E-01
1,2,4-Trimethylbenzene	4.8E-03 [#]	2.6E-03	2.6E-03 [#]	2.6E-03	ND	4.1E-01
Benzyl Chloride*	5.0E-02	1.9E-03	5.5E-03 [#]	1.9E-03	ND	2.8E-01
1,3-Dichlorobenzene	1.3E-02	2.6E-03	4.9E-03 [#]	2.6E-03	ND	4.1E-01
1,4-Dichlorobenzene	5.3E-03 [#]	2.4E-03	ND	2.4E-03	ND	3.9E-01
1,2-Dichlorobenzene	1.7E-02	2.6E-03	8.7E-03	2.6E-03	ND	4.1E-01
d-Limonene	ND	2.4E-03	2.6E-03 [#]	2.4E-03	ND	3.9E-01
1,2-Dibromo-3-chloropropane	ND	1.7E-03	ND	1.7E-03	ND	2.6E-01
1,2,4-Trichlorobenzene	1.2E-02	2.8E-03	6.0E-03 [#]	2.8E-03	ND	4.4E-01
Naphthalene	7.5E-02	3.1E-03	9.6E-02	3.1E-03	1.0E+01	4.9E-01
Hexachlorobutadiene	ND	2.4E-03	ND	2.4E-03	ND	3.9E-01

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Table D6. VOC emissions factors (carbon mass balance method) in each of the high plastic and KMC waste runs.

Compound	HP-1		HP-2		KMC	
	EF	Method detection limit	EF	Method detection limit	EF	Method detection limit
mg/kg waste						
Propene	1.5E+00	9.3E-03	3.0E-02	2.9E-03	2.0E-01	1.2E-02
Dichlorodifluoromethane (CFC 12)	ND	1.1E-02	ND	3.5E-03	ND	1.5E-02
Chloromethane*	1.4E-01	9.9E-03	7.2E-02	3.1E-03	7.5E-02	1.3E-02
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	1.3E-02	ND	3.9E-03	ND	1.6E-02
Vinyl Chloride*	5.7E-01	1.1E-02	2.5E-02	3.5E-03	9.0E-02	1.5E-02
1,3-Butadiene*	ND	1.4E-02	ND	4.5E-03	ND	1.9E-02
Bromomethane*	ND	1.3E-02	5.2E-03 [#]	3.9E-03	ND	1.6E-02
Chloroethane*	6.8E-02	1.1E-02	ND	3.5E-03	ND	1.5E-02
Ethanol	ND	5.3E-02	ND	1.7E-02	ND	6.7E-02
Acetonitrile	1.1E-01	1.2E-02	1.0E-01	3.7E-03	1.1E-01	1.5E-02
Acrolein*	5.1E-01	1.1E-02	1.4E-02	3.5E-03	1.5E-01	1.5E-02
Acetone	ND	5.1E-02	1.7E-01	1.6E-02	4.7E-01	6.5E-02
Trichlorofluoromethane	ND	1.1E-02	ND	3.5E-03	ND	1.5E-02
2-Propanol (Isopropyl Alcohol)	ND	2.8E-02	ND	8.6E-03	ND	3.5E-02
Acrylonitrile*	1.8E-01	1.1E-02	1.2E-02	3.5E-03	7.9E-02	1.5E-02
1,1-Dichloroethene	ND	1.1E-02	ND	3.5E-03	ND	1.5E-02
Methylene Chloride*	2.4E-02 [#]	1.1E-02	2.2E-02	3.5E-03	6.2E-02	1.5E-02
3-Chloro-1-propene (Allyl Chloride)*	2.0E-02 [#]	1.1E-02	6.2E-03 [#]	3.3E-03	1.6E-02 [#]	1.3E-02
Trichlorotrifluoroethane	ND	1.1E-02	ND	3.5E-03	ND	1.5E-02
Carbon Disulfide*	2.5E-02 [#]	9.9E-03	1.3E-01	3.1E-03	2.3E-02 [#]	1.3E-02
trans-1,2-Dichloroethene	ND	1.3E-02	ND	3.9E-03	ND	1.6E-02
1,1-Dichloroethane	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
Methyl tert-Butyl Ether	ND	1.1E-02	ND	3.5E-03	ND	1.5E-02
Vinyl Acetate*	ND	4.3E-02	2.8E-02 [#]	1.3E-02	ND	5.5E-02
2-Butanone (MEK)	1.1E-01	1.4E-02	4.1E-02	4.3E-03	1.5E-01	1.8E-02
cis-1,2-Dichloroethene	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
Ethyl Acetate	ND	2.3E-02	ND	7.2E-03	ND	3.0E-02
n-Hexane	ND	9.9E-03	5.2E-03 [#]	3.1E-03	1.8E-02 [#]	1.3E-02
Chloroform*	2.7E-02 [#]	1.1E-02	2.5E-02	3.5E-03	ND	1.5E-02
Tetrahydrofuran (THF)	ND	1.3E-02	ND	4.1E-03	ND	1.6E-02
1,2-Dichloroethane*	3.0E-02 [#]	1.1E-02	ND	3.3E-03	ND	1.3E-02
1,1,1-Trichloroethane*	ND	1.1E-02	ND	3.5E-03	ND	1.5E-02
Benzene*	1.0E+01	6.3E-02	4.1E+00	3.3E-02	1.6E+01	1.3E-01
Carbon Tetrachloride*	ND	9.9E-03	ND	3.1E-03	ND	1.3E-02

Cyclohexane	ND	1.9E-02	ND	5.9E-03	ND	2.4E-02
1,2-Dichloropropane	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
Bromodichloromethane	ND	9.9E-03	1.2E-02	3.1E-03	ND	1.3E-02
Trichloroethene	ND	9.3E-03	ND	2.9E-03	ND	1.2E-02
1,4-Dioxane	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
Methyl Methacrylate*	ND	2.0E-02	ND	6.4E-03	ND	2.6E-02
n-Heptane	ND	1.1E-02	5.2E-03 [#]	3.5E-03	ND	1.5E-02
cis-1,3-Dichloropropene	ND	9.3E-03	ND	2.9E-03	ND	1.2E-02
4-Methyl-2-pentanone	ND	1.1E-02	3.5E-03 [#]	3.3E-03	ND	1.3E-02
trans-1,3-Dichloropropene	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
1,1,2-Trichloroethane	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
Toluene*	2.4E-01	1.1E-02	8.9E-02	3.5E-03	7.1E+00	1.5E-01
2-Hexanone	1.2E-02 [#]	1.1E-02	ND	3.3E-03	4.3E-02	1.3E-02
Dibromochloromethane	ND	1.1E-02	2.3E-02	3.3E-03	ND	1.3E-02
1,2-Dibromoethane	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
n-Butyl Acetate	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
n-Octane	ND	1.2E-02	ND	3.7E-03	ND	1.5E-02
Tetrachloroethene	ND	9.3E-03	ND	2.9E-03	ND	1.2E-02
Chlorobenzene*	1.9E-01	1.1E-02	1.3E-02	3.3E-03	6.6E-02	1.3E-02
Ethylbenzene	7.7E-02	1.1E-02	ND	3.3E-03	2.4E+00	1.3E-02
m,p-Xylenes*	4.2E-02 [#]	2.0E-02	ND	6.2E-03	5.8E-01	2.6E-02
Bromoform	ND	9.9E-03	5.2E-02	3.1E-03	ND	1.3E-02
Styrene*	ND	9.9E-03	ND	3.1E-03	1.9E-02 [#]	1.3E-02
o-Xylene*	ND	9.9E-03	ND	3.1E-03	3.2E-01	1.3E-02
n-Nonane	ND	9.9E-03	ND	3.1E-03	ND	1.3E-02
1,1,2,2-Tetrachloroethane	ND	9.9E-03	ND	3.1E-03	ND	1.3E-02
Cumene*	ND	9.9E-03	ND	3.1E-03	8.4E-02	1.3E-02
alpha-Pinene	ND	9.3E-03	ND	2.9E-03	ND	1.2E-02
n-Propylbenzene	ND	1.1E-02	ND	3.3E-03	6.5E-02	1.3E-02
4-Ethyltoluene	ND	1.1E-02	ND	3.3E-03	ND	1.3E-02
1,3,5-Trimethylbenzene	ND	1.1E-02	ND	3.3E-03	3.2E-02 [#]	1.3E-02
1,2,4-Trimethylbenzene	ND	9.9E-03	ND	3.1E-03	5.8E-02	1.3E-02
Benzyl Chloride*	8.7E-03 [#]	7.2E-03	3.6E-03 [#]	2.3E-03	8.2E-02	9.3E-03
1,3-Dichlorobenzene	1.1E-02 [#]	9.9E-03	ND	3.1E-03	ND	1.3E-02
1,4-Dichlorobenzene	ND	9.3E-03	ND	2.9E-03	ND	1.2E-02
1,2-Dichlorobenzene	2.7E-02 [#]	9.9E-03	3.3E-03 [#]	3.1E-03	2.4E-02 [#]	1.3E-02
d-Limonene	ND	9.3E-03	ND	2.9E-03	ND	1.2E-02
1,2-Dibromo-3-chloropropane	ND	6.5E-03	ND	2.1E-03	ND	8.4E-03
1,2,4-Trichlorobenzene	ND	1.1E-02	4.3E-03 [#]	3.3E-03	ND	1.3E-02
Naphthalene	4.4E-02	1.2E-02	8.7E-01	3.7E-03	3.4E+00	1.5E-02
Hexachlorobutadiene	ND	9.3E-03	ND	2.9E-03	ND	1.2E-02

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Table D7. VOC emissions factors (carbon mass balance method) in each of the FSR waste runs.

Compound	FSR-1		FSR-2	
	EF	Method detection limit	EF	Method detection limit
	mg/kg waste			
Propene	5.5E+00	1.1E-01	3.4E-01	2.7E-03
Dichlorodifluoromethane (CFC 12)	ND	1.3E-02	ND	3.2E-03
Chloromethane*	1.2E+00	1.2E-02	4.6E-02	2.9E-03
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	1.6E-02	ND	3.6E-03
Vinyl Chloride*	8.4E-01	1.3E-02	6.0E-02	3.2E-03
1,3-Butadiene*	ND	1.7E-02	ND	4.2E-03
Bromomethane*	3.9E-02 [#]	1.6E-02	6.6E-03 [#]	3.6E-03
Chloroethane*	4.8E-02	1.3E-02	4.4E-03 [#]	3.2E-03
Ethanol	ND	6.4E-02	ND	1.5E-02
Acetonitrile	ND	1.4E-02	2.2E-01	3.5E-03
Acrolein*	2.9E+00	1.3E-02	2.0E-01	3.2E-03
Acetone	5.8E+00	6.2E-02	1.5E+00	1.5E-02
Trichlorofluoromethane	ND	1.3E-02	ND	3.2E-03
2-Propanol (Isopropyl Alcohol)	ND	3.4E-02	ND	8.0E-03
Acrylonitrile*	8.3E-01	1.3E-02	4.4E-02	3.2E-03
1,1-Dichloroethene	ND	1.3E-02	ND	3.2E-03
Methylene Chloride*	8.6E-02	1.3E-02	3.5E-02	3.2E-03
3-Chloro-1-propene (Allyl Chloride)*	3.4E-01	1.3E-02	1.4E-01	3.0E-03
Trichlorotrifluoroethane	ND	1.3E-02	ND	3.2E-03
Carbon Disulfide*	2.9E-02 [#]	1.2E-02	6.9E-03 [#]	2.9E-03
trans-1,2-Dichloroethene	ND	1.6E-02	ND	3.6E-03
1,1-Dichloroethane	ND	1.3E-02	ND	3.0E-03
Methyl tert-Butyl Ether	ND	1.3E-02	ND	3.2E-03
Vinyl Acetate*	1.8E+00	5.2E-02	6.5E-01	1.3E-02
2-Butanone (MEK)	2.6E+00	1.7E-02	1.4E+00	3.9E-02
cis-1,2-Dichloroethene	ND	1.3E-02	ND	3.0E-03
Ethyl Acetate	ND	2.8E-02	ND	6.6E-03
n-Hexane	1.0E-01	1.2E-02	8.2E-03 [#]	2.9E-03
Chloroform*	2.5E-02 [#]	1.3E-02	6.6E-03 [#]	3.2E-03
Tetrahydrofuran (THF)	7.2E-02	1.6E-02	ND	3.8E-03
1,2-Dichloroethane*	ND	1.3E-02	ND	3.0E-03
1,1,1-Trichloroethane*	ND	1.3E-02	ND	3.2E-03
Benzene*	2.6E+01	1.3E-01	1.0E+00	3.0E-03
Carbon Tetrachloride*	ND	1.2E-02	ND	2.9E-03
Cyclohexane	ND	2.4E-02	ND	5.6E-03

1,2-Dichloropropane	ND	1.3E-02	ND	3.0E-03
Bromodichloromethane	ND	1.2E-02	ND	2.9E-03
Trichloroethene	ND	1.1E-02	ND	2.7E-03
1,4-Dioxane	3.4E-02 [#]	1.3E-02	ND	3.0E-03
Methyl Methacrylate*	ND	2.5E-02	ND	5.9E-03
n-Heptane	1.0E-01	1.3E-02	1.0E-02	3.2E-03
cis-1,3-Dichloropropene	3.3E-02 [#]	1.1E-02	1.3E-02	2.7E-03
4-Methyl-2-pentanone	6.2E-02	1.3E-02	ND	3.0E-03
trans-1,3-Dichloropropene	3.1E-02 [#]	1.3E-02	1.6E-02	3.0E-03
1,1,2-Trichloroethane	ND	1.3E-02	ND	3.0E-03
Toluene*	2.8E+00	1.3E-02	4.1E-01	3.2E-03
2-Hexanone	3.1E-01	1.3E-02	3.0E-01	3.0E-03
Dibromochloromethane	ND	1.3E-02	ND	3.0E-03
1,2-Dibromoethane	ND	1.3E-02	ND	3.0E-03
n-Butyl Acetate	ND	1.3E-02	ND	3.0E-03
n-Octane	8.6E-02	1.4E-02	ND	3.5E-03
Tetrachloroethene	ND	1.1E-02	ND	2.7E-03
Chlorobenzene*	3.1E-01	1.3E-02	5.7E-02	3.0E-03
Ethylbenzene	8.9E-01	1.3E-02	1.4E-01	3.0E-03
m,p-Xylenes*	2.1E-01	2.4E-02	6.4E-02	5.7E-03
Bromoform	ND	1.2E-02	ND	2.9E-03
Styrene*	ND	1.2E-02	ND	2.9E-03
o-Xylene*	1.0E-01	1.2E-02	3.6E-02	2.9E-03
n-Nonane	3.9E-02	1.2E-02	ND	2.9E-03
1,1,2,2-Tetrachloroethane	ND	1.2E-02	ND	2.9E-03
Cumene*	4.7E-02	1.2E-02	6.7E-03 [#]	2.9E-03
alpha-Pinene	ND	1.1E-02	ND	2.7E-03
n-Propylbenzene	3.0E-02 [#]	1.3E-02	1.1E-02	3.0E-03
4-Ethyltoluene	ND	1.3E-02	ND	3.0E-03
1,3,5-Trimethylbenzene	2.8E-02 [#]	1.3E-02	9.6E-03	3.0E-03
1,2,4-Trimethylbenzene	ND	1.2E-02	3.8E-02	2.9E-03
Benzyl Chloride*	2.8E-01	8.8E-03	4.6E-02	2.1E-03
1,3-Dichlorobenzene	3.5E-02 [#]	1.2E-02	1.6E-02	2.9E-03
1,4-Dichlorobenzene	1.4E-02 [#]	1.1E-02	5.6E-03 [#]	2.7E-03
1,2-Dichlorobenzene	6.6E-02	1.2E-02	2.3E-02	2.9E-03
d-Limonene	ND	1.1E-02	ND	2.7E-03
1,2-Dibromo-3-chloropropane	ND	8.0E-03	ND	1.9E-03
1,2,4-Trichlorobenzene	3.3E-02 [#]	1.3E-02	1.9E-02	3.0E-03
Naphthalene	5.4E+00	1.4E-01	4.4E-01	3.5E-03
Hexachlorobutadiene	ND	1.1E-02	ND	2.7E-03

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Table D8. VOC emissions factors (carbon mass balance method) in four 10 min samples from standard waste run 3.

Compound	SW-3 00:00 - 00:10		SW-3 00:11 - 00:30		SW-3 02:10 - 02:32		SW-3 03:09 - 03:39	
	EF	MDL	EF	MDL	EF	MDL	EF	MDL
mg/kg waste								
Propene	4.7E+00	4.5E-02	1.6E-01	2.5E-03	8.8E-02	3.1E-03	2.5E-02	1.8E-03
Dichlorodifluoromethane (CFC 12)	ND	5.5E-02	5.9E-03 [#]	3.1E-03	8.1E-03 [#]	3.7E-03	ND	2.2E-03
Chloromethane*	3.7E-01	4.9E-02	6.9E-02	2.8E-03	4.1E-02	3.3E-03	4.6E-03 [#]	1.9E-03
1,2-Dichloro-1,1,2,2-tetrafluoroethane (CFC 114)	ND	6.2E-02	ND	3.5E-03	ND	4.2E-03	ND	2.5E-03
Vinyl Chloride*	3.9E-01	5.5E-02	4.6E-01	3.1E-03	9.3E-02	3.7E-03	5.7E-03 [#]	2.2E-03
1,3-Butadiene*	2.4E-01	7.1E-02	ND	4.0E-03	ND	4.8E-03	ND	2.8E-03
Bromomethane*	ND	6.2E-02	9.3E-03 [#]	3.5E-03	5.3E-03 [#]	4.2E-03	3.5E-03 [#]	2.5E-03
Chloroethane*	ND	5.5E-02	ND	3.1E-03	ND	3.7E-03	ND	2.2E-03
Ethanol	8.1E-01	2.6E-01	ND	1.5E-02	ND	1.8E-02	ND	1.0E-02
Acetonitrile	1.9E-01	5.8E-02	9.2E-02	3.3E-03	4.5E-01	3.9E-03	3.1E-02	2.3E-03
Acrolein*	3.6E+00	5.5E-02	2.1E-01	3.1E-03	5.2E-02	3.7E-03	1.8E-02	2.2E-03
Acetone	ND	2.4E-01	5.6E-01	1.4E-02	1.2E+00	1.7E-02	1.8E-01	1.0E-02
Trichlorofluoromethane	ND	5.5E-02	ND	3.1E-03	ND	3.7E-03	ND	2.2E-03
2-Propanol (Isopropyl Alcohol)	2.4E+00	1.4E-01	2.4E-01	7.7E-03	7.9E-02	9.3E-03	2.5E-02	5.4E-03
Acrylonitrile*	1.2E-01 [#]	5.5E-02	1.3E-01	3.1E-03	1.4E-01	3.7E-03	4.7E-03 [#]	2.2E-03
1,1-Dichloroethene	ND	5.5E-02	4.6E-03 [#]	3.1E-03	ND	3.7E-03	ND	2.2E-03
Methylene Chloride*	ND	5.5E-02	5.8E-02	3.1E-03	2.2E-02	3.7E-03	5.3E-03 [#]	2.2E-03
3-Chloro-1-propene (Allyl Chloride)*	ND	5.2E-02	2.6E-02	2.9E-03	6.0E-03 [#]	3.5E-03	3.2E-03 [#]	2.0E-03
Trichlorotrifluoroethane	ND	5.5E-02	ND	3.1E-03	ND	3.7E-03	ND	2.2E-03
Carbon Disulfide*	7.0E-02 [#]	4.9E-02	1.2E-02	2.8E-03	5.8E-01	3.3E-03	1.7E-01	1.9E-03
trans-1,2-Dichloroethene	ND	6.2E-02	ND	3.5E-03	ND	4.2E-03	ND	2.5E-03
1,1-Dichloroethane	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
Methyl tert-Butyl Ether	ND	5.5E-02	ND	3.1E-03	ND	3.7E-03	ND	2.2E-03
Vinyl Acetate*	4.2E-01 [#]	2.1E-01	4.5E-02	1.2E-02	ND	1.4E-02	2.1E-02 [#]	8.4E-03
2-Butanone (MEK)	2.6E-01	6.8E-02	7.7E-02	3.9E-03	2.3E-01	4.6E-03	3.9E-02	2.7E-03
cis-1,2-Dichloroethene	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
Ethyl Acetate	ND	1.1E-01	ND	6.4E-03	ND	7.8E-03	ND	4.5E-03
n-Hexane	ND	4.9E-02	6.7E-03 [#]	2.8E-03	1.8E-02	3.3E-03	8.5E-03	1.9E-03
Chloroform*	1.5E-01 [#]	5.5E-02	6.5E-03 [#]	3.1E-03	1.6E-01	3.7E-03	2.2E-02	2.2E-03
Tetrahydrofuran (THF)	ND	6.5E-02	3.9E-03 [#]	3.6E-03	8.9E-03 [#]	4.4E-03	ND	2.5E-03
1,2-Dichloroethane*	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
1,1,1-Trichloroethane*	ND	5.5E-02	ND	3.1E-03	ND	3.7E-03	ND	2.2E-03
Benzene*	3.2E+01	5.2E-02	2.4E+00	2.9E-02	2.2E+00	7.1E-03	5.2E-01	2.0E-03
Carbon Tetrachloride*	ND	4.9E-02	ND	2.8E-03	ND	3.3E-03	ND	1.9E-03
Cyclohexane	ND	9.4E-02	ND	5.3E-03	ND	6.5E-03	ND	3.7E-03
1,2-Dichloropropane	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03

Bromodichloromethane	ND	4.9E-02	ND	2.8E-03	2.9E-02	3.3E-03	5.7E-03 [#]	1.9E-03
Trichloroethene	ND	4.5E-02	ND	2.5E-03	ND	3.1E-03	1.9E-03 [#]	1.8E-03
1,4-Dioxane	ND	5.2E-02	4.1E-02	2.9E-03	ND	3.5E-03	ND	2.0E-03
Methyl Methacrylate*	ND	1.0E-01	ND	5.6E-03	ND	6.9E-03	ND	4.0E-03
n-Heptane	ND	5.5E-02	1.0E-02	3.1E-03	2.5E-02	3.7E-03	1.9E-02	2.2E-03
cis-1,3-Dichloropropene	ND	4.5E-02	5.0E-03 [#]	2.5E-03	ND	3.1E-03	ND	1.8E-03
4-Methyl-2-pentanone	ND	5.2E-02	4.4E-03 [#]	2.9E-03	2.0E-02	3.5E-03	3.5E-03 [#]	2.0E-03
trans-1,3-Dichloropropene	ND	5.2E-02	4.8E-03 [#]	2.9E-03	ND	3.5E-03	ND	2.0E-03
1,1,2-Trichloroethane	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
Toluene*	9.9E-01	5.5E-02	2.5E-02	3.1E-03	6.9E-02	3.7E-03	1.7E-02	2.2E-03
2-Hexanone	ND	5.2E-02	1.5E-02	2.9E-03	2.2E-02	3.5E-03	9.3E-03	2.0E-03
Dibromochloromethane	ND	5.2E-02	ND	2.9E-03	6.5E-03 [#]	3.5E-03	3.3E-03 [#]	2.0E-03
1,2-Dibromoethane	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
n-Butyl Acetate	ND	5.2E-02	1.8E-02	2.9E-03	ND	3.5E-03	ND	2.0E-03
n-Octane	ND	5.8E-02	7.2E-03 [#]	3.3E-03	1.0E-02 [#]	3.9E-03	1.4E-02	2.3E-03
Tetrachloroethene	1.3E+01	4.5E-02	ND	2.5E-03	ND	3.1E-03	ND	1.8E-03
Chlorobenzene*	1.9E-01	5.2E-02	8.7E-02	2.9E-03	2.2E-02	3.5E-03	6.0E-03 [#]	2.0E-03
Ethylbenzene	2.3E-01	5.2E-02	6.8E-03 [#]	2.9E-03	5.0E-03 [#]	3.5E-03	2.3E-03 [#]	2.0E-03
m,p-Xylenes*	ND	9.7E-02	1.2E-02 [#]	5.5E-03	ND	6.7E-03	ND	3.9E-03
Bromoform	ND	4.9E-02	ND	2.8E-03	ND	3.3E-03	7.9E-03	1.9E-03
Styrene*	4.1E-01	4.9E-02	ND	2.8E-03	ND	3.3E-03	ND	1.9E-03
o-Xylene*	ND	4.9E-02	7.4E-03 [#]	2.8E-03	3.8E-03 [#]	3.3E-03	2.4E-03 [#]	1.9E-03
n-Nonane	ND	4.9E-02	2.8E-03 [#]	2.8E-03	ND	3.3E-03	7.1E-03	1.9E-03
1,1,2,2-Tetrachloroethane	ND	4.9E-02	ND	2.8E-03	ND	3.3E-03	ND	1.9E-03
Cumene*	ND	4.9E-02	ND	2.8E-03	ND	3.3E-03	ND	1.9E-03
alpha-Pinene	ND	4.5E-02	ND	2.5E-03	ND	3.1E-03	ND	1.8E-03
n-Propylbenzene	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
4-Ethyltoluene	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
1,3,5-Trimethylbenzene	ND	5.2E-02	ND	2.9E-03	ND	3.5E-03	ND	2.0E-03
1,2,4-Trimethylbenzene	ND	4.9E-02	3.3E-03 [#]	2.8E-03	ND	3.3E-03	ND	1.9E-03
Benzyl Chloride*	ND	3.6E-02	2.3E-02	2.0E-03	7.2E-03 [#]	2.4E-03	4.2E-03 [#]	1.4E-03
1,3-Dichlorobenzene	5.2E-02 [#]	4.9E-02	8.4E-03	2.8E-03	7.7E-03 [#]	3.3E-03	2.0E-03 [#]	1.9E-03
1,4-Dichlorobenzene	ND	4.5E-02	5.3E-03 [#]	2.5E-03	4.1E-03 [#]	3.1E-03	ND	1.8E-03
1,2-Dichlorobenzene	1.3E-01 [#]	4.9E-02	3.3E-02	2.8E-03	1.2E-02	3.3E-03	3.1E-03 [#]	1.9E-03
d-Limonene	ND	4.5E-02	3.5E-03 [#]	2.5E-03	ND	3.1E-03	2.6E-03 [#]	1.8E-03
1,2-Dibromo-3-chloropropane	ND	3.2E-02	ND	1.8E-03	ND	2.2E-03	ND	1.3E-03
1,2,4-Trichlorobenzene	7.5E-02 [#]	5.2E-02	8.4E-03 [#]	2.9E-03	1.3E-02	3.5E-03	3.1E-03 [#]	2.0E-03
Naphthalene	1.1E+00	5.8E-02	3.5E-01	3.3E-03	3.9E+00	8.0E-03	7.8E-01	2.3E-03
Hexachlorobutadiene	ND	4.5E-02	ND	2.5E-03	ND	3.1E-03	ND	1.8E-03

* On EPA's list of hazardous air pollutants. ND – not detected. # Less than three times the detection limit.

Appendix E: PCDDs/PCDFs – Full data set

Table E1. PCDD/PCDF concentration for each homologue and test run.

Homologue	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	ng/m ³ at 7% O ₂							
TeCDD Total	1.3E+00	1.2E+00	2.0E+00	2.0E+00	1.5E+00	9.5E+00	6.8E+00	6.3E+00
PeCDD Total	2.6E-01	2.5E-01	4.6E-01	4.3E-01	3.3E-01	8.5E-01	1.2E+00	1.4E+00
HxCDD Total	5.7E-02	4.2E-02	1.1E-01	6.0E-02	5.0E-02	7.9E-02	2.4E-01	2.3E-01
HpCDD Total	1.7E-02	9.3E-03	3.4E-02	1.5E-02	2.0E-02	1.4E-02	5.7E-02	4.6E-02
OCDD	1.1E-02	4.4E-03	1.2E-02	8.1E-03	1.4E-02	5.5E-03	1.8E-02	1.3E-02
TeCDF Total	4.7E+01	3.4E+01	4.9E+01	4.8E+01	3.7E+01	4.4E+01	7.7E+01	9.1E+01
PeCDF Total	7.0E+00	6.1E+00	8.4E+00	8.6E+00	7.3E+00	6.7E+00	1.2E+01	1.7E+01
HxCDF Total	5.6E-01	5.3E-01	8.9E-01	7.8E-01	7.0E-01	4.8E-01	1.2E+00	1.5E+00
HpCDF Total	6.2E-02	5.2E-02	1.3E-01	1.1E-01	1.5E-01	5.3E-02	1.6E-01	1.5E-01
OCDF	7.9E-03	5.1E-03	1.2E-02	1.8E-02	3.0E-02	7.7E-03	0.0E+00	1.1E-02
Sum PCDD Total	1.6E+00	1.5E+00	2.6E+00	2.6E+00	2.0E+00	1.0E+01	8.4E+00	8.0E+00
Sum PCDF Total	5.4E+01	4.1E+01	5.8E+01	5.8E+01	4.6E+01	5.1E+01	9.0E+01	1.1E+02
Sum PCDD/PCDF Total	5.6E+01	4.3E+01	6.1E+01	6.0E+01	4.8E+01	6.1E+01	9.8E+01	1.2E+02

Table E2. PCDD/PCDF concentration for each Toxic Equivalent Factor (TEF) isomer and test run, in ng TEQ/m³ at 7% O₂.

Isomer	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	ng TEQ/m ³ at 7% O ₂							
2,3,7,8 - TCDD	5.9E-02	6.0E-02	7.1E-02	5.9E-02	4.7E-02	6.1E-02	2.3E-01	1.6E-01
1,2,3,7,8 - PeCDD	2.9E-02	2.8E-02	4.9E-02	3.9E-02	3.5E-02	4.5E-02	1.1E-01	1.3E-01
1,2,3,4,7,8 - HxCDD	3.0E-04	1.7E-04	6.1E-04	3.1E-04	2.5E-04	3.0E-04	9.8E-04	1.1E-03
1,2,3,6,7,8 - HxCDD	4.1E-04	3.0E-04	8.6E-04	4.1E-04	4.4E-04	4.9E-04	1.5E-03	1.6E-03
1,2,3,7,8,9 - HxCDD	3.3E-04	2.5E-04	7.2E-04	3.3E-04	3.2E-04	3.5E-04	1.0E-03	1.0E-03
1,2,3,4,6,7,8 - HpCDD	8.4E-05	4.4E-05	1.6E-04	7.7E-05	1.0E-04	6.8E-05	2.7E-04	2.0E-04
1,2,3,4,6,7,8,9 - OCDD	3.2E-06	1.3E-06	3.7E-06	2.4E-06	4.2E-06	1.6E-06	5.5E-06	3.8E-06
2,3,7,8 - TCDF	8.6E-02	7.2E-02	9.8E-02	9.1E-02	8.0E-02	8.2E-02	1.6E-01	1.9E-01
1,2,3,7,8 - PeCDF	1.0E-02	8.5E-03	1.2E-02	1.1E-02	1.0E-02	8.6E-03	1.7E-02	2.2E-02
2,3,4,7,8 - PeCDF	4.9E-02	4.5E-02	8.0E-02	6.4E-02	5.5E-02	5.1E-02	1.2E-01	1.5E-01
1,2,3,4,7,8 - HxCDF	5.7E-03	5.2E-03	8.7E-03	6.8E-03	6.0E-03	4.0E-03	1.1E-02	1.4E-02
1,2,3,6,7,8 - HxCDF	6.4E-03	5.8E-03	9.8E-03	7.8E-03	7.4E-03	4.8E-03	1.3E-02	1.5E-02
1,2,3,7,8,9 - HxCDF	1.0E-03	6.4E-04	1.8E-03	1.5E-03	1.6E-03	9.7E-04	2.2E-03	2.7E-03
2,3,4,6,7,8 - HxCDF	3.0E-03	2.2E-03	6.2E-03	4.9E-03	5.1E-03	3.2E-03	8.3E-03	9.6E-03
1,2,3,4,6,7,8 - HpCDF	3.4E-04	2.9E-04	7.1E-04	5.9E-04	7.1E-04	2.6E-04	9.1E-04	8.8E-04

1,2,3,4,7,8,9 - HpCDF	5.8E-05	3.4E-05	8.6E-05	9.4E-05	1.3E-04	3.7E-05	1.0E-04	8.7E-05
1,2,3,4,6,7,8,9 - OCDF	2.4E-06	1.5E-06	3.6E-06	5.4E-06	9.1E-06	2.3E-06	5.9E-06	3.2E-06
Sum PCDD TEQ	8.9E-02	8.9E-02	1.2E-01	9.9E-02	8.4E-02	1.1E-01	3.4E-01	3.0E-01
Sum PCDF TEQ	1.6E-01	1.4E-01	2.2E-01	1.9E-01	1.7E-01	1.5E-01	3.2E-01	4.1E-01
Sum PCDD/PCDF TEQ	2.5E-01	2.3E-01	3.4E-01	2.9E-01	2.5E-01	2.6E-01	6.6E-01	7.1E-01

Table E3. PCDD/PCDF emissions factor for each homologue and test run in ng/kg waste (carbon mass balance method).

Homologue	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1
	ng/kg waste						
TeCDD Total	7.4E+00	1.2E+01	1.9E+01	1.5E+01	8.9E+01	7.9E+01	5.9E+01
PeCDD Total	1.5E+00	2.8E+00	4.0E+00	3.2E+00	8.0E+00	1.4E+01	1.3E+01
HxCDD Total	2.6E-01	6.8E-01	5.6E-01	4.8E-01	7.4E-01	2.8E+00	2.2E+00
HpCDD Total	5.7E-02	2.1E-01	1.4E-01	1.9E-01	1.4E-01	6.6E-01	4.2E-01
OCDD	2.7E-02	7.6E-02	7.5E-02	1.3E-01	5.1E-02	2.1E-01	1.2E-01
TeCDF Total	2.1E+02	3.0E+02	4.5E+02	3.5E+02	4.1E+02	8.9E+02	8.5E+02
PeCDF Total	3.7E+01	5.2E+01	8.0E+01	6.9E+01	6.3E+01	1.4E+02	1.5E+02
HxCDF Total	3.2E+00	5.5E+00	7.3E+00	6.6E+00	4.5E+00	1.4E+01	1.4E+01
HpCDF Total	3.2E-01	7.7E-01	1.1E+00	1.4E+00	4.9E-01	1.8E+00	1.4E+00
OCDF	3.1E-02	7.5E-02	1.7E-01	2.9E-01	7.2E-02	2.3E-01	1.0E-01
Sum PCDD Total	9.3E+00	1.6E+01	2.4E+01	1.9E+01	9.8E+01	9.7E+01	7.4E+01
Sum PCDF Total	2.5E+02	3.6E+02	5.4E+02	4.3E+02	4.7E+02	1.0E+03	1.0E+03
Sum PCDD/PCDF Total	2.6E+02	3.7E+02	5.6E+02	4.5E+02	5.7E+02	1.1E+03	1.1E+03

Table E4. PCDD/PCDF emissions factor for each TEF isomer and test run in ng TEQ/kg waste (carbon mass balance method).

Isomer	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	ng TEQ/kg waste						
2,3,7,8 - TCDD	3.7E-01	4.4E-01	5.5E-01	4.5E-01	5.7E-01	2.6E+00	1.5E+00
1,2,3,7,8 - PeCDD	1.7E-01	3.0E-01	3.7E-01	3.4E-01	4.2E-01	1.2E+00	1.2E+00
1,2,3,4,7,8 - HxCDD	1.0E-03	3.7E-03	2.9E-03	2.3E-03	2.8E-03	1.1E-02	9.8E-03
1,2,3,6,7,8 - HxCDD	1.8E-03	5.3E-03	3.9E-03	4.1E-03	4.5E-03	1.7E-02	1.5E-02
1,2,3,7,8,9 - HxCDD	1.5E-03	4.5E-03	3.1E-03	3.0E-03	3.3E-03	1.2E-02	9.5E-03
1,2,3,4,6,7,8 - HpCDD	2.7E-04	1.0E-03	7.2E-04	9.9E-04	6.3E-04	3.1E-03	1.8E-03
1,2,3,4,6,7,8,9 - OCDD	8.0E-06	2.3E-05	2.3E-05	4.0E-05	1.5E-05	6.4E-05	3.6E-05
2,3,7,8 - TCDF	4.4E-01	6.1E-01	8.5E-01	7.6E-01	7.6E-01	1.8E+00	1.8E+00
1,2,3,7,8 - PeCDF	5.2E-02	7.7E-02	1.0E-01	9.5E-02	8.0E-02	1.9E-01	2.1E-01
2,3,4,7,8 - PeCDF	2.7E-01	5.0E-01	6.0E-01	5.2E-01	4.8E-01	1.3E+00	1.4E+00

1,2,3,4,7,8 - HxCDF	3.2E-02	5.4E-02	6.4E-02	5.7E-02	3.7E-02	1.2E-01	1.3E-01
1,2,3,6,7,8 - HxCDF	3.5E-02	6.1E-02	7.3E-02	7.0E-02	4.5E-02	1.5E-01	1.4E-01
1,2,3,7,8,9 - HxCDF	3.9E-03	1.1E-02	1.4E-02	1.5E-02	9.1E-03	2.5E-02	2.5E-02
2,3,4,6,7,8 - HxCDF	1.3E-02	3.9E-02	4.6E-02	4.8E-02	2.9E-02	9.6E-02	8.9E-02
1,2,3,4,6,7,8 - HpCDF	1.8E-03	4.4E-03	5.5E-03	6.8E-03	2.5E-03	1.1E-02	8.2E-03
1,2,3,4,7,8,9 - HpCDF	2.0E-04	5.3E-04	8.8E-04	1.3E-03	3.5E-04	1.2E-03	8.1E-04
1,2,3,4,6,7,8,9 - OCDF	9.2E-06	2.2E-05	5.0E-05	8.6E-05	2.2E-05	6.9E-05	3.0E-05
Sum PCDD TEQ	5.4E-01	7.5E-01	9.3E-01	8.0E-01	1.0E+00	3.9E+00	2.8E+00
Sum PCDF TEQ	8.5E-01	1.4E+00	1.8E+00	1.6E+00	1.4E+00	3.7E+00	3.8E+00
Sum PCDD/PCDF TEQ	1.4E+00	2.1E+00	2.7E+00	2.4E+00	2.4E+00	7.6E+00	6.6E+00

Table E5. PCDD/PCDF emissions factor for each homologue and test run in ng/kg waste input.

Homologue	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	ng/kg waste input							
TeCDD Total	8.5E+00	9.0E+00	1.4E+01	2.0E+01	2.1E+01	6.9E+01	5.1E+01	6.2E+01
PeCDD Total	1.7E+00	1.8E+00	3.2E+00	4.2E+00	4.5E+00	6.2E+00	9.0E+00	1.4E+01
HxCDD Total	3.8E-01	3.1E-01	7.6E-01	5.8E-01	6.8E-01	5.7E-01	1.8E+00	2.3E+00
HpCDD Total	1.2E-01	6.9E-02	2.3E-01	1.5E-01	2.7E-01	1.0E-01	4.2E-01	4.5E-01
OCDD	7.0E-02	3.2E-02	8.5E-02	7.8E-02	1.9E-01	4.0E-02	1.4E-01	1.3E-01
TeCDF Total	3.1E+02	2.5E+02	3.4E+02	4.7E+02	5.0E+02	3.1E+02	5.7E+02	9.0E+02
PeCDF Total	4.6E+01	4.5E+01	5.8E+01	8.4E+01	9.8E+01	4.8E+01	8.7E+01	1.6E+02
HxCDF Total	3.7E+00	3.9E+00	6.2E+00	7.5E+00	9.4E+00	3.5E+00	8.8E+00	1.5E+01
HpCDF Total	4.1E-01	3.8E-01	8.7E-01	1.1E+00	2.0E+00	3.8E-01	1.2E+00	1.5E+00
OCDF	5.2E-02	3.7E-02	8.4E-02	1.7E-01	4.1E-01	5.6E-02	1.5E-01	1.1E-01
Sum PCDD Total	1.1E+01	1.1E+01	1.8E+01	2.5E+01	2.6E+01	7.6E+01	6.2E+01	7.9E+01
Sum PCDF Total	3.6E+02	3.0E+02	4.0E+02	5.6E+02	6.2E+02	3.7E+02	6.6E+02	1.1E+03
Sum PCDD/PCDF Total	3.7E+02	3.1E+02	4.2E+02	5.9E+02	6.4E+02	4.4E+02	7.3E+02	1.2E+03

Table E6. PCDD/PCDF emissions factor for each TEF isomer and test run in ng TEQ/kg waste input.

Isomer	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	ng TEQ/kg waste input							
2,3,7,8 - TCDD	3.9E-01	4.4E-01	4.9E-01	5.7E-01	6.4E-01	4.4E-01	1.7E+00	1.6E+00
1,2,3,7,8 - PeCDD	1.9E-01	2.0E-01	3.4E-01	3.8E-01	4.8E-01	3.2E-01	7.8E-01	1.3E+00
1,2,3,4,7,8 - HxCDD	2.0E-03	1.2E-03	4.2E-03	3.0E-03	3.3E-03	2.2E-03	7.3E-03	1.0E-02
1,2,3,6,7,8 - HxCDD	2.7E-03	2.2E-03	6.0E-03	4.0E-03	5.9E-03	3.5E-03	1.1E-02	1.6E-02
1,2,3,7,8,9 - HxCDD	2.2E-03	1.8E-03	5.0E-03	3.2E-03	4.3E-03	2.6E-03	7.5E-03	1.0E-02
1,2,3,4,6,7,8 - HpCDD	5.6E-04	3.2E-04	1.1E-03	7.5E-04	1.4E-03	4.9E-04	2.0E-03	2.0E-03
1,2,3,4,6,7,8,9 - OCDD	2.1E-05	9.7E-06	2.6E-05	2.4E-05	5.7E-05	1.2E-05	4.1E-05	3.8E-05
2,3,7,8 - TCDF	5.7E-01	5.3E-01	6.8E-01	8.8E-01	1.1E+00	5.9E-01	1.2E+00	1.9E+00
1,2,3,7,8 - PeCDF	6.9E-02	6.3E-02	8.6E-02	1.1E-01	1.3E-01	6.2E-02	1.2E-01	2.2E-01
2,3,4,7,8 - PeCDF	3.2E-01	3.3E-01	5.6E-01	6.2E-01	7.4E-01	3.7E-01	8.6E-01	1.5E+00
1,2,3,4,7,8 - HxCDF	3.8E-02	3.8E-02	6.0E-02	6.6E-02	8.2E-02	2.9E-02	7.9E-02	1.4E-01
1,2,3,6,7,8 - HxCDF	4.2E-02	4.3E-02	6.8E-02	7.6E-02	1.0E-01	3.5E-02	9.6E-02	1.5E-01
1,2,3,7,8,9 - HxCDF	6.6E-03	4.7E-03	1.2E-02	1.5E-02	2.2E-02	7.0E-03	1.6E-02	2.7E-02
2,3,4,6,7,8 - HxCDF	2.0E-02	1.6E-02	4.3E-02	4.8E-02	6.8E-02	2.3E-02	6.2E-02	9.5E-02
1,2,3,4,6,7,8 - HpCDF	2.2E-03	2.2E-03	4.9E-03	5.7E-03	9.6E-03	1.9E-03	6.8E-03	8.8E-03
1,2,3,4,7,8,9 - HpCDF	3.9E-04	2.5E-04	6.0E-04	9.2E-04	1.8E-03	2.7E-04	7.8E-04	8.6E-04
1,2,3,4,6,7,8,9 - OCDF	1.6E-05	1.1E-05	2.5E-05	5.2E-05	1.2E-04	1.7E-05	4.4E-05	3.2E-05
Sum PCDD TEQ	5.9E-01	6.5E-01	8.4E-01	9.6E-01	1.1E+00	7.8E-01	2.5E+00	2.9E+00
Sum PCDF TEQ	1.1E+00	1.0E+00	1.5E+00	1.8E+00	2.2E+00	1.1E+00	2.4E+00	4.1E+00
Sum PCDD/PCDF TEQ	1.7E+00	1.7E+00	2.4E+00	2.8E+00	3.4E+00	1.9E+00	4.9E+00	7.0E+00

Appendix F: PAHs – Full data set

Table F1. PAH₁₆ concentrations for each test run.

PAH	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	µg/m ³ at 7% O ₂							
Naphthalene	827	22	3081	103	131	332	392	35
Acenaphthylene	156	19	290	56	64	25	184	14
Acenaphthene	3.6	1.5	4.0	0.89	1.4	4.8	6.2	2.4
Fluorene	44	9.3	67	17	20	32	70	11
Phenanthrene	259	137	646	230	146	332	658	141
Anthracene	16	8.2	35	10	10	20	55	11
Fluoranthene	139	124	292	132	144	113	179	108
Pyrene	161	158	317	138	150	128	183	131
Benzo(a)anthracene	2.4	2.1	21	1.9	3.8	2.5	4.7	3.2
Chrysene	3.1	2.5	37	3.9	4.9	4.3	7.9	5.4
Benzo(b)fluoranthene	2.8	ND	45	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	2.9	ND	36	ND	ND	ND	ND	ND
Benzo(a)pyrene	3.5	ND	47	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	1.2	ND	57	0.31	ND	ND	0.22	ND
Dibenz(a,h)anthracene	0.15	ND	4.4	ND	ND	ND	ND	ND
Benzo(ghi)perylene	1.8	ND	81	0.46		0.30	0.35	ND
SUM 16-EPA PAH	1624	482	5061	694	676	994	1741	461

ND – not detected

Table F2. PAH₁₆ emissions factors for each test run in mg/kg waste (carbon mass balance method). No CEM during SW-1.

PAH	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	mg/kg waste						
Naphthalene	0.13	19	0.97	1.2	3.1	4.5	0.32
Acenaphthylene	0.11	1.8	0.52	0.61	0.23	2.1	0.13
Acenaphthene	0.0094	0.025	0.008	0.013	0.045	0.071	0.022
Fluorene	0.056	0.41	0.16	0.19	0.30	0.81	0.10
Phenanthrene	0.83	4.0	2.2	1.4	3.1	7.6	1.3
Anthracene	0.050	0.21	0.10	0.095	0.19	0.63	0.10
Fluoranthene	0.75	1.8	1.2	1.4	1.1	2.08	1.0
Pyrene	0.96	2.0	1.3	1.4	1.2	2.1	1.2
Benzo(a)anthracene	0.013	0.13	0.018	0.036	0.024	0.054	0.030
Chrysene	0.015	0.23	0.037	0.046	0.040	0.092	0.050
Benzo(b)fluoranthene	ND	0.28	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	ND	0.22	ND	ND	ND	ND	ND
Benzo(a)pyrene	ND	0.29	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	ND	0.35	0.0029	ND	ND	0.0025	ND

Dibenz(a,h)anthracene	ND	0.027	ND	ND	ND	ND	ND
Benzo(ghi)perylene	ND	0.50	0.0043	ND	0.0028	0.0041	ND
SUM 16-EPA PAH	2.9	31	6.5	6.4	9.3	20	4.3

ND – not detected

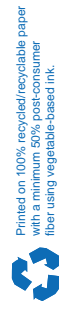
Table F3. PAH₁₆ emissions factors for each test run in mg/kg waste input.

PAH	SW-1	SW-2	SW-3	HP-1	HP-2	KMC	FSR-1	FSR-2
	mg/kg Waste input							
Naphthalene	5.5	0.16	21	1.0	1.8	2.4	2.9	0.34
Acenaphthylene	1.0	0.14	2.0	0.54	0.86	0.18	1.4	0.14
Acenaphthene	0.024	0.011	0.028	0.0087	0.019	0.035	0.046	0.023
Fluorene	0.29	0.068	0.46	0.16	0.28	0.23	0.52	0.11
Phenanthrene	1.7	1.0	4.5	2.2	2.0	2.4	4.9	1.4
Anthracene	0.11	0.060	0.24	0.099	0.14	0.15	0.41	0.11
Fluoranthene	0.92	0.91	2.0	1.3	2.0	0.82	1.3	1.1
Pyrene	1.1	1.2	2.2	1.3	2.0	0.93	1.4	1.3
Benzo(a)anthracene	0.016	0.015	0.15	0.019	0.051	0.018	0.035	0.032
Chrysene	0.020	0.019	0.26	0.038	0.066	0.031	0.059	0.053
Benzo(b)fluoranthene	0.018	ND	0.31	ND	ND	ND	ND	ND
Benzo(k)fluoranthene	0.019	ND	0.25	ND	ND	ND	ND	ND
Benzo(a)pyrene	0.023	ND	0.33	ND	ND	ND	ND	ND
Indeno(1,2,3-cd)pyrene	0.0078	ND	0.39	0.0030	ND	ND	0.0016	ND
Dibenz(a,h)anthracene	0.0010	ND	0.030	ND	ND	ND	ND	ND
Benzo(ghi)perylene	0.012	ND	0.56	0.0045	ND	0.0022	0.0026	ND
SUM 16-EPA PAH	11	3.5	35	6.7	9.1	7.2	13	4.6

ND – not detected



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